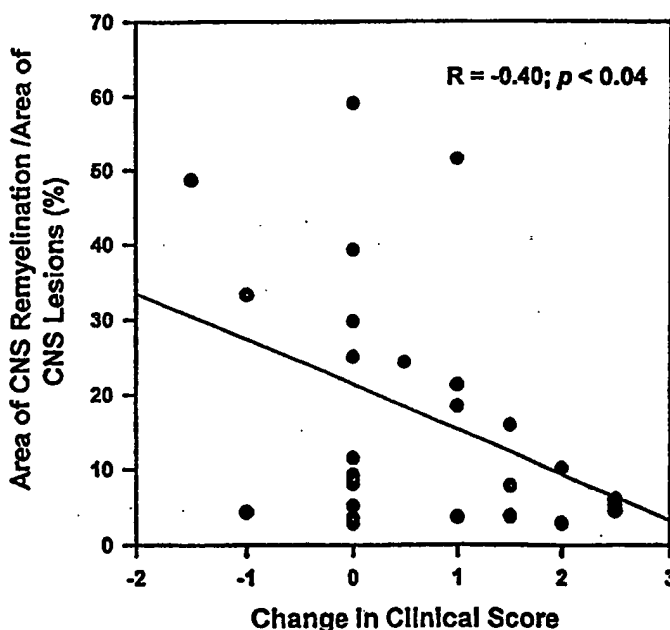




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : C12N 15/13, A61K 39/395, C07K 16/18, C12N 5/20, 5/06		A1	(11) International Publication Number: WO 95/30004
			(43) International Publication Date: 9 November 1995 (09.11.95)
(21) International Application Number: PCT/US95/05262		(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ, UG).	
(22) International Filing Date: 27 April 1995 (27.04.95)			
(30) Priority Data: 08/236,520 29 April 1994 (29.04.94) US			
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		Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.	

(54) Title: MONOCLONAL ANTIBODIES WHICH PROMOTE CENTRAL NERVOUS SYSTEM REMYELINATION



(57) Abstract

Monoclonal IgM antibodies which promote central nervous system remyelination when given to a mammal afflicted with a demyelinating disease are disclosed. These antibodies show multi-organ autoreactivity, and recognize both surface and cytoplasmic determinants on glial cells.

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MONOCLONAL ANTIBODIES WHICH PROMOTE
CENTRAL NERVOUS SYSTEM REMYELINATION

Background

Multiple sclerosis (MS) is a chronic, frequently
5 progressive, inflammatory central nervous system (CNS)
disease characterized pathologically by primary
demyelination, usually without initial axonal injury. The
etiology and pathogenesis of MS are unknown. Several
immunological features of MS, and its moderate association
10 with certain major histocompatibility complex alleles, has
prompted the speculation that MS is an immune-mediated
disease (Hafler, D.A. and Weiner, H.L., Immunol. Today,
10:104-107 (1989); Compston, D.A.S., "Genetic
susceptibility to multiple sclerosis," In: McAlpine's
15 Multiple Sclerosis (Matthews, B. ed), pp 301-319, London:
Churchil Livingstone (1991); Olsson, T., Curr. Opin.
Neurol. Neurosurg., 5:195-202 (1992)).

An autoimmune hypothesis is supported by the
experimental autoimmune (allergic) encephalomyelitis (EAE)
20 model, where injection of certain myelin components into
genetically susceptible animals leads to T cell-mediated
CNS demyelination (Kabat, E.A. et al., J. Exp. Med.,
85:117-129 (1947); Lublin, F.D., Spinger Semin.
Immunopathol., 8:197-208 (1985)). However, specific
25 autoantigens and pathogenic myelin-reactive T cells have
not been definitively identified in the CNS of MS patients,
nor is MS associated with other autoimmune diseases. An
alternative hypothesis, based upon epidemiological data
(Martyn, C., "The epidemiology of multiple sclerosis. In:
30 McAlpine's Multiple Sclerosis, (Matthews, B. ed), pp 3-40,
London: Churchill Livingstone (1991) is that an
environmental factor, perhaps an unidentified virus,
precipitates an inflammatory response in the CNS, which

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leads to either direct or indirect ("bystander") myelin destruction, potentially with an induced autoimmune component (Lampert, P.W., Am. J. Path. 91:176-208 (1978)). This hypothesis is supported by evidence that several
5 naturally occurring viral infections, both in humans (Rice, G.P.A., Curr. Opin. Neurol. Neurosurg., 5:188-194 (1992)) and animals (Dal Canto, M.C. and Rabinowitz, S.G., Ann. Neurol., 11:109-127 (1982)), can cause demyelination. One commonly utilized experimental viral model is induced by
10 Theiler's murine encephalomyelitis virus (TMEV) (Dal Canto, M.C., and Lipton, H.L., Am. J. Path., 88:497-500 (1977)).

The limited efficacy of current therapies for MS and other demyelinating diseases (Goodkin, D.E. et al., Clev. Clin. J. Med., 59:63-74 (1992)), has stimulated interest in
15 novel therapies to ameliorate these diseases (Martin, R., et al., Ann. Rev. Immunol., 10:153-187 (1992); Steinman, L., Adv. Immunol., 49:357-379 (1992); Weiner, H.L., et al., Science 259:1321-1324 (1993)). However, due to the apparently complex etiopathogenesis of these diseases,
20 potentially involving both environmental and autoimmune factors, the need still exists for an effective treatment of these demyelinating disorders.

Summary of the Invention

The present invention relates to the promotion, or
25 stimulation, of remyelination of central nervous system axons in a mammal. Specifically, the present invention relates to methods of stimulating the remyelination of central nervous system (CNS) axons using a monoclonal antibody obtained from a mammal immunized with spinal cord
30 homogenate (SCH) from a normal mammal (i.e., uninfected with any demyelinating disease). This monoclonal (mAb) is referred to herein as SCH94.03, and the hybridoma producing this monoclonal antibody has been deposited on April 28, 1994, under the terms of the Budapest Treaty, with the

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American Type Culture Collection (ATCC) and given ATCC Accession No. CRL 11627. As demonstrated herein, treatment of a mammal afflicted with a demyelinating disease using the mAb, SCH94.03, resulted in an increase in CNS
5 remyelination compared to mice treated with control mAb.

The present invention also relates to methods of treating demyelinating diseases in mammals, such as multiple sclerosis in humans, and viral diseases of the central nervous system of humans and domestic animals, such
10 as post-infectious encephalomyelitis, or prophylactically inhibiting the initiation or progression of demyelination in these disease states, using the SCH94.03 monoclonal antibody. This invention further relates to in vitro methods of producing, and stimulating the proliferation
15 of, glial cells, such as oligodendrocytes, and the use of these glial cells to treat demyelinating diseases.

Brief Description of the Figures

Figure 1 is a graph depicting the dose-response characteristics of antibody-mediated proliferation of cells
20 in mixed rat brain culture.

Figure 2 is a graph depicting the temporal profile of antibody-mediated proliferation of cells in mixed rat brain culture.

Figure 3A-3D shows light and electron micrographs of
25 CNS remyelination promoted by mAb SCH94.03. (A) Light micrograph of spinal cord section from a chronically infected SJL/J mouse treated with SCH94.03 showing CNS remyelination. (B) Light micrograph of spinal cord section from a chronically infected SJL/J mouse treated with a
30 control IgM showing extensive demyelination, and the relative absence of remyelination. Inflammatory cells, including macrophages with ingested myelin debris are indicated by arrows. The asterisk indicates a representative naked axon. (C) Light micrograph of spinal

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cord section with normal myelin. (D) Electron micrograph of spinal cord section from an animal treated with SCH94.03 showing multiple axons with abnormally thin myelin sheaths relative to axon diameter. The star in the upper right-hand corner indicates an axon with normal myelin sheath thickness. Arrowheads point to astrocytic processes, which are intimately associated with remyelinated axons. Scale bars represent 13 μm in A-C, and 2 μm in D.

10 Figure 4 is a graph depicting the correlation between the change in clinical disease and morphological remyelination.

Figure 5 is a graph depicting the dose-response relationship between treatment with mAb SCH94.03 and CNS remyelination. Area of CNS remyelination (●) and percentage of lesion area with remyelination (○) in animals treated with various doses of mAb SCH94.03.

Figure 6 shows a Western blot of TMEV proteins. Lysates from infected L2 fibroblast cells were separated by SDS-PAGE, transferred to nitrocellulose, and blotted with SCH94.03 (lane 1), SCH94.32 (lane 2), serum from susceptible mice chronically infected with TMEV (lane 3), and polyclonal rabbit anti-TMEV IgG (lane 4). Molecular weights are indicated on the left in kilodaltons (kDa). The position and identification of the major TMEV capsid proteins are indicated on the right.

Figure 7A-7D shows the immunostaining of cultured glial cells and frozen CNS tissue sections with mAb SCH94.03. Scale bars represent 15 μm .

30 Figure 8A-8C shows the results of SCH94.03 (Figure 8A) and control IgMs (Figure 8B and 8C) binding to protein antigens as determined by ELISA.

Figure 9 shows the results of SCH94.03 F(ab2)' binding to protein antigens as determined by ELISA.

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Figure 10A-10C show the results of SCH94.03 (Figure 10A) and control IgMs (Figure 10B and 10C) binding to chemical haptens as determined by ELISA,

Figure 11 shows the alignment of the immunoglobulin
5 light and heavy chain variable region sequences of SCH94.03 and control IgM, CH12, and germline Ig gene segments (SEQ ID NOS:1-11).

Detailed Description of the Invention

The present invention relates to the promotion, or
10 stimulation, of remyelination of central nervous system axons in a mammal. Specifically, the present invention relates to methods of stimulating the remyelination of central nervous system (CNS) axons using a monoclonal antibody obtained from a mammal immunized with spinal cord
15 homogenate from a normal mammal (i.e., uninfected with any demyelinating disease). The antigen reactivity of the monoclonal antibody, an IgM monoclonal antibody referred to herein as SCH94.03 (also referred to herein as SCH94.32) has been characterized as described in the present
20 invention using several biochemical and molecular assays, including immunohistochemistry, immunocytochemistry, Western blotting, solid-phase enzyme-linked immunosorbant assays (ELISA), and Ig variable region sequencing. The hybridoma producing monoclonal antibody SCH94.03 has been
25 deposited on April 28, 1994, under the terms of the Budapest Treaty, with the American Type Culture Collection (ATCC) and has been given ATCC Accession No. CRL 11627. All restrictions upon the availability of the deposit material will be irrevocably removed upon granting of the
30 patent.

The present invention also relates to methods of treating demyelinating diseases in mammals, such as multiple sclerosis in humans, and viral diseases of the central nervous system of humans and domestic animals, such

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as post-infectious encephalomyelitis, using the SCH94.03 monoclonal antibody. Methods of prophylactic treatment using the mAb to inhibit the initiation or progression of demyelinating diseases are also encompassed by this invention.

Selection of SCH mAbs to promote CNS remyelination

A panel of monoclonal antibodies (mAbs) derived from splenocytes of uninfected SJL/J mice injected with SCH was constructed as described in detail in Example 1. After the initial fusion and cloning, 2 of the 95 wells with viable Ig-secreting hybridomas contained mAb with significant binding to SCH as demonstrated by ELISA. Hybridoma cells from these two wells, called the 79 and 94 series, were subcloned by limiting dilution and screened again for binding to SCH by ELISA. For the 79 series hybridomas, 14 out of 49 clones were positive by SCH ELISA, while for the 94 series, 17 out of 32 were positive for binding to SCH. Based upon the ELISA data, two 79 series hybridomas (SCH79.08 and SCH79.27), both of which also reacted with myelin basic protein (MBP) by ELISA, and three 94 series hybridomas (SCH94.03, SCH94.11, and SCH94.32), none of which reacted with MBP, were chosen for ascites production and in vivo transfer experiments.

MAbs Promote Proliferation of Glial Cells

As described in Example 2, the mAbs were tested for their ability to promote proliferation of glial cells in vitro. As shown in Table 1, rat optic nerve cells grown in the presence of mAb 94.02 or 79.27 incorporated more [³H]thymidine than controls grown in media alone or with an isotype-matched control mAb. Data is shown from one of five experiments which showed a similar result.

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TABLE 1.

Monoclonal Antibodies to Spinal Cord Homogenate Promote						
Incorporation of [³ H]Thymidine in Cultured Optic Nerve Glial Cells						
Additive in Medium	µg/ml	CPM Mean + SE	Stimulation Index Isotype Control	P	Stimulation Index PBS	P
mAb 94.32	3	3,642 ± 364	2.68	<0.01	2.17	<0.01
mAb 79.27	3	2,326 ± 182	1.71	<0.01	1.38	<0.05
Isotype Control	3	1,359 ± 82	1.00	--	0.81	--
PBS	--	1,680 ± 203	1.23	--	1.00	--
mAb 94.32	10	4,663 ± 114	2.78	<0.002	1.90	<0.01
mAb 79.27	10	2,711 ± 176	1.62	NS	1.11	NS
Isotype Control	10	1,678 ± 213	1.00	--	0.68	--
PBS	--	2,451 ± 946	1.46	--	1.00	--
mAb 94.32	30	3,855 ± 639	4.01	<0.03	2.44	<0.002
mAb 79.27	30	4,037 ± 371	4.20	<0.04	2.56	<0.003
Isotype Control	30	962 ± 191	1.00	--	0.61	--
PBS	--	1,578 ± 231	1.64	--	1.00	--

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The dose-response characteristics of antibody-mediated proliferation were then examined. As shown in Figure 1, maximal stimulation with 94.03 was seen at 100 ng/ml. Control myeloma IgMs MOPC 104E and TEPC 183 (data not shown) 5 also stimulated the mixed rat brain cultures to proliferate. However, the maximal effect was seen at a 10-fold higher concentration than that seen with the mAbs.

The temporal profile of antibody-mediated proliferation was also examined as shown in Figure 2. On day 8, after 10 culture initiation, 100 ng/ml antibody was added to the cultures (time 0). Cells were harvested at 24 hour

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intervals; [³H]thymidine was present for the final 24 hours of culture to measure the total proliferation during the interval. The maximal stimulation with 94.03 was seen at 72 hours after antibody addition. Similar results were obtained with 94.32. None of the isotype control antibodies showed any significant proliferation throughout the 120 hours of culture. These data demonstrates that both mAbs 94.32 and 94.03 induce proliferation of glial cells of mixed rat brain culture. This proliferation is maximal at an antibody concentration of 100 ng/ml and a culture period of 72 hours after antibody addition.

CNS Remyelination Promoted by mAbs SCH94.03 and SCH94.32

As described in Example 3, SJL/J mice chronically infected with TMEV were treated with a total mAb dose of 0.5 mg iv or 5.0 mg ip divided into twice weekly doses for 4-5 weeks. CNS remyelination was measured by a quantitative morphological assessment on ten spinal cord cross-sections from each mouse. The criterion for CNS remyelination was abnormally thin myelin sheaths relative to axonal diameter. The data are composite of six experiments and are presented as the mean \pm SEM, where n indicates the number of mice. Statistical comparisons for remyelination data were made with the cumulative values from both IgM and buffer only controls using a modified rank sum test. The number of demyelinated lesions and the area of demyelination were not significantly different between treatment groups assessed by a one-way ANOVA. For control IgMs, we used myelomas MOPC 104E and ABPC 22 (both from Sigma), and TB5-1, an anti-mycobacteria mAb.

SJL/J mice chronically infected with TMEV and treated with either mAb SCH94.03 or SCH94.32 showed significantly greater CNS remyelination than animals treated with either isotype-matched control mAb or buffer only (Table 2).

Table 2.

Monoclonal antibodies SCH94.03 and SCH94.32 promote CNS remyelination							
Treatment	n	Number of Remyelinated Lesions	Area of Remyel (mm ²)	p-value	Number of Demyelinated Lesions	Area of Lesion (mm ²)	Area Remyelination /Area Lesion (%)
SCH94.03	12	12.8 ± 2.6	0.35 ± 0.09	<0.0025	25.8 ± 2.6	1.09 ± 0.19	28.9 ± 3.8
SCH94.32	12	12.3 ± 2.3	0.42 ± 0.11	<0.0001	24.9 ± 2.8	1.46 ± 0.21	26.7 ± 4.2
IgM control	13	6.7 ± 1.2	0.11 ± 0.02	--	29.9 ± 2.0	1.70 ± 0.28	7.7 ± 1.8
Buffer only	11	5.1 ± 1.1	0.06 ± 0.01	--	27.7 ± 2.7	1.11 ± 0.29	6.5 ± 1.2

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Remyelination was seen with either iv or ip injections. SCH94.03- or SCH94.32-treated animals had approximately 2-3-fold more remyelinated lesions, and a 3-4-fold larger total area of CNS remyelination than control animals. When a cumulative statistical comparison was made using these two parameters of therapeutic effectiveness, the CNS remyelination induced by mAbs SCH94.03 and SCH94.32 was highly significant ($p < 0.005$; Table 2). In a chronic progressive disease like TMEV infection, the extent of CNS repair is a direct function of the extent of CNS damage. Both the number and area of CNS lesions were not different between treatment groups, indicating similar disease severity (Table 2). When CNS remyelination was expressed as the percentage of lesion area showing remyelination, approximately one-third of the cumulative demyelinated lesion area showed CNS remyelination in mice treated with either mAb SCH94.03 or SCH94.32 (Table 2).

Morphology of CNS Remyelination

CNS remyelination was readily identified morphologically both by light and electron microscopy (Figure 3A-3D). Figure 3A shows a remyelinated lesion from an animal treated with SCH94.03. The majority of axons in the lesion show morphologic evidence of repair, with abnormally thin myelin sheaths relative to axonal diameter (Ludwin, S.K. "Remyelination in the central nervous system of the mouse," In: THE PATHOLOGY OF THE MYELINATED AXON (Adachi M, Hirano A, Aronson SM eds), pp 49-79, Tokyo: Igaku-Shoin Ltd. (1985); Ludwin, S.K., Adv. Neurol., 47:215-254 (1988)). For comparison, Figure 3B shows a demyelinated lesion, with minimal remyelination, whereas Figure 3C is an area of normal myelin, with thickly myelinated axons. Within remyelinated lesions (Figure 3A), there were 15.3 ± 1.0 (mean \pm SEM) myelinated axons per 100 μm^2 , compared to only 1.1 ± 0.2 myelinated axons per 100 μm^2 .

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in demyelinated lesions (Figure 3B). Figure 3C shows a light micrograph of spinal cord section with normal myelin. By electron microscopy, CNS remyelination was especially evident (Figure 3D). Almost every axon in the field has evidence of new myelin formation, although the degree of remyelination (ie. myelin thickness) is variable between individual axons, suggesting different stages of the repair process. The ratio of myelin thickness to axonal diameter was 0.08 ± 0.01 (mean \pm SEM; $n = 25$ axons) for remyelinated axons compared to 0.21 ± 0.01 ($n = 34$ axons) for normally myelinated axons.

Correlation Between Clinical Disease and Morphological Remyelination

The correlation of morphological remyelination with clinical signs of disease improvement was assessed as described in Example 3. At each treatment injection, mice were assessed clinically as described in Example 3. The change in clinical score was correlated with the percentage of lesion area showing remyelination (Figure 4).

Morphological remyelination is represented as the percentage of lesion area showing CNS remyelination. A change in clinical score of 0 represent stable disease over the treatment period (4-5 weeks), whereas a positive change indicates worsening of clinical disease, and a negative change indicates improvement. Data represent individual animals from all treatment groups. A positive change in clinical score indicates worsening of disease. Using data from all treatment groups, the change in clinical score showed a moderate but significant negative correlation ($R = -0.40$; $p < 0.04$) with the percentage of lesion area showing remyelination. Although few animals actually improved clinically (Δ clinical score < 0), animals with an increase in disease severity (Δ clinical score > 0) tended to have less morphological remyelination, while animals that

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remained stable clinically (Δ clinical score = 0) showed the most remyelination. A similar negative correlation was obtained when the other quantitative measures of remyelination were used (the number of remyelinated lesions and the area of remyelination) as shown in Table 2. These data demonstrate that remyelination quantitated by morphology is associated with slowing of clinical disease progression.

Titration of mAb SCH94.03 Dose and CNS Remyelination

10 For the initial treatment experiments, a total mAb dose of 25 mg/kg for iv injections and 250 mg/kg for ip injection was empirically chosen. To assess the dose-response characteristics, and to determine the minimal amount of mAb
15 were treated with various ip doses of SCH94.03. Both the number of remyelinated lesions (data not shown) and the total area of remyelination (Figure 5) increased significantly with larger doses of SCH94.03. Remyelination was quantitated as described for Table 2. Data are the mean
20 values of 4-5 animals per mAb dose, with the final cumulative dose indicated on the graph. SEM averaged 35% of the mean. There was no statistical difference assessed by one-way ANOVA in the number of demyelinated lesions or the area of demyelination between treatment groups, indicating
25 similar extent of disease in all animals. The number of demyelinated lesions and area of lesions were 33.2 ± 7.5 and 1.25 ± 0.43 for the 1000 μ g group, 31.8 ± 8 and 1.11 ± 0.31 for the 100 μ g group, 23.8 ± 3.4 and 0.54 ± 0.14 for the 10 μ g group, and 29.0 ± 6.5 and 0.74 ± 0.20 for the buffer only
30 group (represented as the 0 dose point on the graph). Animals treated with 100 μ g control IgM (MOPC 104E) had remyelination scores similar to control animals treated with buffer only. The positive correlation between the dose of mAb SCH94.03 and CNS remyelination was especially striking

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when the severity of CNS disease was taken into account. When CNS repair was expressed as the percentage of lesion area showing remyelination, mice treated with a total dose of 1000, 100, or 10 μ g of SCH94.03 had 6-, 5-, and 4-fold more remyelination than control animals, respectively (Figure 5). Mice given as little as 10 μ g of SCH94.03 ip (0.5 mg/kg) showed evidence of enhanced CNS remyelination. These data indicated that mAb SCH94.03 and CNS remyelination had a positive dose-response relationship, and that very small quantities of mAb were needed to promote myelin repair.

Antigen Specificity of SCH94.03 and SCH94.32.

Although mAbs SCH94.03 and SCH94.32 were generated from splenocytes of uninfected mice, and screened against SCH94.03 from uninfected mice, it was directly assessed whether either mAb could react with TMEV capsid proteins or inhibit viral infectivity in vitro. By Western blotting (Figure 6), SCH94.03 and SCH94.32 did not react with any TMEV proteins recognized by either serum from chronically infected mice or polyclonal IgG from rabbits injected with purified TMEV (Rodriguez, M., et al., Ann. Neurol., 13:426-433 (1983)). Western blot of lysates from control mock infected L2 cells showed single bands with the serum from chronically infected animals and the polyclonal rabbit anti-TMEV IgG at 32 and 43 kDa, respectively, but no reactivity with SCH94.03 or SCH94.32.

In addition, no significant inhibition of TMEV infectivity in vitro with up to 5 μ g/ml of either SCH94.03 or SCH94.32, was observed under assay conditions where 50% neutralization was observed with a 1:34,000 dilution of serum from chronically infected animals. These results indicated that the therapeutic effect of SCH94.03 and SCH94.32 was not due to direct inhibition of the virus.

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To initially characterize the antigens recognized by mAbs SCH94.03 and SCH94.32, various cell lines derived from glial (rat C6, mouse G26-20, human U373MG and U87MG), neural (human neuroblastoma), fibroblast (mouse L and 3T3), epithelial (human SCC-9 carcinoma), and lymphocytic (mouse CTLL2) origin were stained. Both mAbs stained internal antigens of all cell lines tested, which indicated that certain antigens recognized by these mAbs were not restricted to unique cell types in vitro. Based on the hypothesis that the therapeutic effect of SCH94.03 and SCH94.32 was due to a CNS-specific interaction, the immunostaining of cultured cells by SCH94.03 and SCH94.32 using the rat glial cell line 5.5B8 was further investigated. This immortalized glial cell line has phenotypic characteristics of both astrocytes, with expression of MBP and 2',3'-cyclic nucleotide 3'-phosphodiesterase (CNP), and low but detectable expression of glial fibrillary acidic protein (GFAP) and the lipids or proteins recognized by the mAbs A2B5 and O4 (Bozyczko, D. et al., Ann. NY Acad. Sci., 605:350-353 (1990)). SCH94.03 and SCH94.32 recognized both a surface and cytoplasmic determinant on 5.5B8 cells. The surface staining was most prominent on small cells which lay on top of a layer of flat, morphologically differentiated cells (Figure 7A). Surface staining was confirmed by flow cytometry on live cells. When the cell membrane was permeabilized by dehydration or brief treatment with a non-ionic detergent to expose internal antigens, the staining pattern was altered considerably (Figure 7B). The cytoplasmic staining was filamentous, with a dense perinuclear network that extended out into the cell processes. This pattern closely resembled the staining pattern of the intermediate filament cytoskeletal protein vimentin. These data indicated that SCH94.03 and SCH94.32 recognized antigens that were not restricted to cells

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derived from the nervous system, but that they did recognize both surface and cytoplasmic determinants on glial cells.

Immunohistochemical staining of frozen mouse, rat, and human tissue confirmed that SCH94.03 and SCH94.32 were not
5 CNS-specific mAbs, but rather showed multi-organ reactivity. Both mAbs immunostained all major organs examined, including the brain, spinal cord, optic nerve, heart, liver, kidney, stomach, and small intestine and skeletal muscle. However, not all cells within an organ stained, suggesting in situ
10 cytological specificity. Within the CNS, SCH94.03 and SCH94.32 stained predominantly blood vessels, ependymal cells, and stellate-shaped cells with the morphological features of glial cells, which were enriched in neonatal cerebellar, periventricular, and brain stem white matter
15 (Figure 7C), and both neonatal and adult optic nerve. Similar glial cells positive for SCH94.03 and SCH94.32 were found in autopsied human brain tissue, especially at the gray-white matter junction (Figure 7D). Identical immunostaining results were obtained with mAb SCH94.32.
20 Immunostaining with a control IgM (MOPC 104E) was negative for all samples and tissue structures which immunostained with SCH94.03 and SCH94.32.

The identification and characterization of an entire family of autoantibodies, referred to as "natural" or
25 "physiological" autoantibodies, has influenced traditional views of autoimmunity and self-reactivity. The natural autoantibodies that have been studied extensively are typically IgMs, although other isotypes have been identified, are reactive toward a wide range of antigens,
30 including cytoskeletal proteins, surface proteins, nucleic acids, phospholipids, bacterial antigens such as lipopolysaccharides, and various chemical haptens (reviewed by Avrameas and Ternynck, Mol. Immunol., 30:1133-1142 (1993)). Natural autoantibodies share extensive idiotypic
35 cross-reactivity or "connectivity", which includes

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expression of similar idiotypes, some of which are expressed by pathogenic autoantibodies, as well as reactivity toward common idiotypes expressed on other antibodies. Molecular analysis has shown that natural autoantibodies are typically
5 encoded by unmutated germline immunoglobulin (Ig) genes, with few if any somatic mutations, and therefore represent a substantial fraction of the Ig repertoire, especially in neonatal animals which have not had extensive exogenous antigen exposure.

10 The function of natural autoantibodies remains enigmatic. Several hypotheses have been proposed based upon their biochemical and molecular characteristics. These include: (1) clearance of senescent or damage tissue, (2) providing a first line of immunological defense in the lag
15 period between pathogen exposure and an Ag-specific immune response, (3) masking autoantigen from a potentially pathogenic autoimmune response, (4) immunomodulation, including shaping of the neonatal immune repertoire via an idiotypic network, and (5) participation in the positive
20 selection of B cells in the bone marrow, similar to the process proposed for T cells in the thymus.

The hypothesis that antibodies SCH94.03 and SCH94.32 were natural autoantibodies was tested. To characterize the antigen reactivities of SCH94.03 and SCH94.32, several
25 biochemical and molecular assays, including immunohistochemistry and immunocytochemistry, Western blotting, solid-phase enzyme-linked immunosorbant assays (ELISA), and Ig variable region sequencing, were used. As described below, for all biochemical assays, SCH94.03 and
30 SCH94.32 were indistinguishable. In addition, SCH94.03 and SCH94.32 had identical Ig variable region sequences, which confirmed that they were the same mAb.

A potential mechanism whereby SCH94.03 could stimulate remyelination in the central nervous system would be to
35 stimulate the proliferation and/or differentiation of cells

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involved in myelinogenesis, primarily oligodendrocytes or their immature precursors. Thus, it was tested whether SCH94.03 stained the surface of various cells. Using immortalized cells, it was determined that SCH94.03 stained 5 two glial cells lines, 5.5B8 (Figure 7A) and 20.2E11, but did not stain the surface of several other glial cells lines (10.1A3, 20.2A40, C6, G26-20), a neuroblastoma cell line (B104), two fibroblast lines (L2, Cos-1), or two myoblastomas (G8, L6). Similar results were obtained with 10 cells isolated from animal tissues and grown in culture. SCH94.03 stained the surface of oligodendrocytes, but not astrocytes, microglia, Schwann cells, myoblasts, or fibroblasts.

The reactivity of SCH94.03 with proteins from glial and 15 lymphoid cell lines, and tissue lysates from brain, liver, and intestine by Western blotting was also assessed. SCH94.03 reacted with multiple bands from all cells and tissues examined, with prominent reactivity toward bands at 50, 95, 120, and >200 kDa. The exact identity of these 20 protein bands has not been determined.

The reactivity of SCH94.03 with several purified protein self-antigens by solid-phase ELISA was determined. (Figure 8A-8C). SCH94.03 showed strong reactivity toward the RBC antigen spectrin, but also showed consistent reactivity 25 toward hemoglobin, actin, tubulin, and vimentin, and thyroglobulin, although to a lesser qualitative degree than toward spectrin. No reactivity was observed with myosin, transferrin, albumin, lysozyme, or myelin basic protein under our assay conditions. Six other monoclonal or myeloma 30 IgM controls XXMEN-OE5 (Figure 8B), A2B5, MOPC104E, TEPC183, 01, and CH12 (Figure 8C), were also tested, and no reactivity with any of the antigens tested was observed.

To confirm the monoclonality of SCH94.03, 18 subclones of SCH94.03 (9 each from SCH94.03 and SCH94.32 parents) were 35 tested for polyreactivity by solid-phase ELISA. All 18

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subclones showed identical reactivity patterns with the panel of protein antigens as the parent SCH94.03. To further support the conclusion that the polyreactivity of SCH94.03 was via its Fab region, we generated F(ab)₂' fragments and assessed their reactivity with the protein antigens by ELISA (Figure 9). SCH94.03 F(ab)₂' fragments showed similar polyreactivity as the whole IgM molecule.

A panel of chemical haptens coupled to bovine serum albumin (BSA) was constructed and used to assess SCH94.03 reactivity by solid-phase ELISA (Figure 10A-10C). SCH94.03 showed strong reactivity toward fluorescein (FL) and 4-hydroxy-3-nitrophenyl acetic acid (NP), moderate reactivity toward phenyloxazolone (PhOx), and weak reactivity toward 2, 4, 6-trinitrophenyl (TNP) and p-azophenylarsonic acid (Ars). No reactivity with p-azophenyltrimethylammonium (TMA), p-azophenylphosphorylcholine (PC), or the carrier protein BSA was detected. Control IgMs (Figure 10B and 10C) showed no significant binding to any of the haptens tested, with the exceptions of CH12 reactivity with TMA, which has been previously reported, and A2B5 reactivity with NP.

It was further investigated whether the Ig light (L) (SEQ ID NOS:1 and 2) and heavy (H) (SEQ ID NOS:6 and 7) chains of SCH94.03 were encoded by germline Ig genes (Figure 11). The light chain variable (V_L) and joining (J_L) region nucleotide sequences from SCH94.03 (SEQ ID NOS:1 and 2) had 99.4% identity with the previously published sequences of the germline V_κ10 (SEQ ID NO:4) and J_κ1 (SEQ ID NO:5) genes, with only two silent changes at the 3' end of both the V_L and J_L regions. The SCH94.03 V_H (SEQ ID NOS:6 and 7) region nucleotide sequence was identical to the previously published germline V_H23 (SEQ ID NO:10) sequence, the J_H region sequence differed from the published germline J_H2 (SEQ ID NO:11) sequence by one nucleotide, at the 5' end of the J region, and the diversity (D) region contained 15

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contiguous nucleotides derived from the germline DFL16.1 gene. There were 8 nucleotides in the V-D junction, and 1 in the D-J junction, which did not correspond to any known germline V or D region genes, and probably represent non-coded (N) nucleotides inserted by the enzyme terminal deoxynucleotide transferase during V-D-J recombination. The only changes from the germline genes in the heavy chain of SCH94.03 occurred at either the V-D or D-J junction, and therefore could represent either N nucleotides or the result of imprecise joining, rather than somatic mutations. In addition, both the light and heavy chain variable regions of SCH94.03 showed extensive sequence similarity with the IgM produced by the B-cell lymphoma CH12 (SEQ. ID NOS:3, 8 and 9) (Figure 11).

15 SCH94.03 is a Natural Autoantibody

These preliminary antigen reactivity results suggest that SCH94.03 is a natural autoantibody. Although this conclusion does not readily present a mechanism as to how SCH94.03 stimulates remyelination in the central nervous system, it does suggest an important physiological function of natural autoantibodies. Autoantibodies that are produced either during normal physiology, or in response to tissue damage and the subsequent release of previously sequestered antigens, might actively participate to promote repair in the damaged tissue. In line with previously proposed functions of natural autoantibodies, this active participation might be to facilitate removal of damaged tissue, mask autoantigens thereby preventing a vigorous pathogenic autoimmune response, modulate the immune response which actually resulted in the tissue destruction, thereby allowing normal endogenous tissue repair to occur, or directly stimulate cells involved in the repair process.

Thus, as a result of the work described herein, it is now demonstrated that an autoantibody generated and screened

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for its autoantigen-binding capability, also promotes CNS remyelination. Mice chronically infected with TMEV and treated either iv or ip with IgM mAbs from hybridomas SCH94.03 or SCH94.32 had significantly more CNS repair than 5 control animals, measured by a detailed quantitative morphological assessment of CNS remyelination. Moreover, preliminary data suggest that the autoantibody, SCH94.03 is also effective in promoting remyelination in mammals afflicted with experimental autoimmune encephalomyelitis 10 (EAE). Thus, it is reasonable to predict that autoantibodies, such as SCH94.03, play a critical role in stopping an immune-mediated process of demyelination in CNS diseases.

Two potential mechanisms can be proposed by which Abs 15 promote remyelination. First, Abs might inhibit some pathogenic component of the disease process, such as virus activity, an immune response which directly induces demyelination, or an immune response which prevents remyelination. If the disease outcome is based upon a 20 balance between tissue destruction and repair, inhibition of pathogenic components would allow a physiological repair response to predominate. Experimental and clinical evidence support this hypothesis. Spontaneous CNS remyelination is seen in MS patients and several experimental models of CNS 25 demyelination as well as described herein, demonstrating spontaneous remyelination in control mice. This indicates that remyelination is a normal physiological response to myelin damage. In addition, treatment of mice chronically infected with TMEV with various immunosuppressive regiments 30 promotes remyelination, but does not decrease demyelination, indicating that there is an immunological component which inhibits remyelination. (Rodriguez, M. and Lindsley, M.D., Neurology, 42:348-357 (1992)). Preliminary immunological function studies have indicated that animals treated with 35 SCH94.03 had similar numbers of B and T (both CD4+ and CD8+)

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cells in their spleens compared to control animals, had similar in vitro splenocyte proliferative responses to mitogens and antigens, and mounted comparable Ab responses to both T cell-dependent and T cell-independent antigens.

5 The second hypothesis is that certain Abs can actively stimulate CNS remyelination, perhaps via stimulation of oligodendrocyte proliferation and/or differentiation in vivo, as has been demonstrated in vitro (Diaz, M. et al., Brain Res., 154:231-239 (1978); Raine, C.S., et al., Lab. Invest., 38:397-403 (1979); Lehrer, G.M. et al., Brain Res., 172:557-560 (1979); Bansal, R. et al., J. Neurosci. Res., 21:260-267 (1988); Benjamins, J.A. and Dyer, C.A., Ann. NY Acad. Sci., 605:90-100 (1990); Dyer, C.A., Mol. Neurobiol., 7:1-22 (1993)). MAb SCH94.03 may directly
10 stimulate precursor glial cells which are known to be present at the edges of both human and experimental CNS lesions which show active remyelination. Alternatively, SCH94.03 may work indirectly, via activation of astrocytes or other accessory cells, which could release factors
15 important for the survival or proliferation of cells in the oligodendroglial lineage. The formation of Ab-antigen complexes in situ with tissue components released upon myelin destruction may also participate in Ab-mediated CNS remyelination. Although SCH94.03 is not CNS-specific, the
20 recognition of both surface and cytoplasmic antigens on glial cells by the mAb supports an active mechanism hypothesis. In contrast to the immunomodulatory hypothesis, which would not necessarily require that Abs have direct access to the CNS, the hypothesis that Abs actively
25 stimulate CNS remyelination implies the prerequisite of direct access to the CNS. This is contrary to the view of the selective permeability of the blood-brain barrier, especially toward large molecules such as pentameric IgM. However, during chronic inflammatory conditions such as TMEV
30 infection or MS, peripheral leukocytes migrate into the CNS,

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indicating an alteration in the blood-brain barrier permeability. Therefore, large proteins such as serum Ig might also enter, via either passive diffusion through "open" endothelium, or perhaps via an unidentified active transport mechanism.

Treatment of Demyelinating Diseases

The results of the experiments described herein have practical applications to multiple sclerosis (MS), EAE, and other related central nervous system demyelinating disorders. Rare examples of spontaneous CNS-type remyelination ("shadow plaques") are found in MS and occasional peripheral nervous system (PNS)-type remyelination is found in demyelinated spinal cord plaques near the root entry zone. Oligodendrocytes are infrequent at the center of the chronic plaques in MS but they appear to proliferate at the periphery of plaques, where they are associated with abortive remyelination. The process of remyelination may correlate with the spontaneous remission and improvements observed clinically in MS. These clinical observations indicate that new myelin formation is possible in MS. The remyelination that has been stimulated in mice with TMEV-induced demyelination by using a mAb may hold promise for therapeutic application in multiple sclerosis.

Of importance clinically is the question of whether morphologic regeneration of thin myelin sheaths contributes to functional recovery. Computer simulations indicate that new myelin formation even by inappropriately thin sheaths improves impulse conduction. Since the axon membrane of normally myelinated fibers is highly differentiated, it is necessary for sodium channels to be present at high density at the node of Ranvier to propagate saltatory conduction. Experimental evidence suggests that newly formed nodes do develop the required high sodium channel density as demonstrated by saxitoxin binding. Data to date suggest

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that remyelination even by inappropriately thin myelin improves conduction in a previously demyelinated axon. Therefore, any strategy to promote this morphologic phenomenon has the potential of producing functional
5 recovery.

The data presented herein demonstrates, for the first time, that administration of a monoclonal antibody to a mammal is capable of stimulating remyelination of central nervous system axons in vivo. Specifically, treatment of
10 chronically infected TMEV-infected mice with as little as 10 ug of SCH94.03 resulted in a 4- to 5-fold increase in the total area of CNS myelination compared to mice treated with a control mAb.

Thus, as a result of the experiments described herein,
15 the method of the present invention can be used to treat mammals, including humans and domestic animals, afflicted with demyelinating disorders, and to stimulate remyelination of the CNS axons. As described herein, an effective amount of the monoclonal antibody can be administered by
20 intravenous (iv) or intraperitoneal (ip) injection. An effective amount of the antibody can vary depending on the size of the mammal being treated, the severity of the disease, the route of administration, and the course of treatment. For example, each dose of mAb administered can
25 range from approximately 0.5 mg/kg to approximately 400 mg/kg, with the preferred range from approximately 0.5 mg/kg to approximately 250 mg/kg. It is important to note that a dose as low as 10 μ g (0.5 mg/kg) was effective in promoting remyelination of CNS axons in mice. The dose of mAb will
30 also depend on the route of administration. For example, an iv dose administered to mice was 0.5 mg/kg, and an ip dose was 5.0 mg/kg. The course of treatment includes the frequency of administration of the mAb (e.g, daily, weekly, or bi-weekly) and the duration of the treatment (e.g, four
35 weeks to four months). Thus, for example, a larger amount

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of mAb can be given daily for four to five weeks, as opposed to a smaller amount of mAb given for four months.

The effectiveness of the amount of the monoclonal antibody being administered can be assessed using any number of clinical criteria, for example, as described in Example 3, including overall appearance of the mammal, the activity of the mammal and the extent of paralysis of the mammal. The effectiveness of the amount of monoclonal antibody necessary to induce remyelination in humans can also be assessed in a double blinded controlled trial. Patients with fixed neurological deficits from demyelinating disease can be treated with monoclonal antibody or controls. Improvement in isometric muscle strength as detected by quantitative biomechanics muscle testing could be used as the primary therapeutic end-point.

An effective amount of the monoclonal antibody can be combined with, or diluted with, an appropriate pharmaceutically acceptable carrier, such as a physiological buffer, or saline solution. Additionally, the monoclonal antibody may be genetically altered, e.g. "humanized" by the substitution of human antibody nucleotide sequences in non-variable regions of the murine mAb to reduce immunogenicity.

In addition to in vivo methods of promoting remyelination, ex vivo methods of stimulating remyelination in CNS axons are also encompassed by the present invention. For example, the monoclonal antibody may be used in vitro to stimulate the proliferation and/or differentiation of glial cells, such as oligodendrocytes, as described in Example 2. These exogenous glial cells can then be introduced into the CNS of mammals using known techniques. Remyelination of CNS axons would be increased by increasing the number of endogenous glial cells present (glial cells, such as oligodendrocytes play a critical role in the production of myelin).

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In vitro methods of producing glial cells, or stimulating the proliferation of glial cells from mixed culture (e.g., rat optic nerve cell, or rat brain cell cultures) are also encompassed by this invention. For example, cells obtained from rat optic nerve, or rat brain, containing glial cells, are cultured as a mixed culture under conditions sufficient to promote growth of the cells. An effective amount of mAb capable of promoting remyelination of CNS axons, such as SCH94.03, is then added to the mixed culture of cells and maintained under conditions sufficient for growth and proliferation of cells. The mAb stimulates the proliferation of glial cells in the mixed culture. Thus the proliferation of glial cells cultured in the presence of the mAb is increased, relative to the proliferation of glial cells grown in the absence of the mAb.

The invention will be further and more specifically illustrated by the following Examples, which are not intended to be limiting in any way.

20 Example 1: Monoclonal Antibody Production, Screening and Purification

Animals

Spleens of two SJL/J mice (Jackson Laboratories, Bar Harbor, ME) that had been injected twice with spinal cord homogenate (SCH) in incomplete Freund's adjuvant were used as the source of B cells for fusion and hybridoma production. Splenocytes were fused with NS-1 myeloma cells using polyethylene glycol, and viable cell fusions were selected with hypoxanthine-aminopterin-thymidine (HAT) media and cloned by limiting dilution as described (Katzmann, J.A. et al., Proc. Nat. Acad. Sci. USA, 78:162-166 (1981)).

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ELISAs

Hybridoma supernatants from viable Ig-producing clones were screened for binding to SCH by an enzyme-linked immunosorbant assay (ELISA). The following antigens were used for screening mAbs: SCH - (10 μ g) reconstituted in carbonate-bicarbonate buffer (pH 8.53), MBP - (1 μ g) dissolved in PBS, GC (1 μ g) dissolved in absolute alcohol, PLP (1 μ g) dissolved in water. PLP was provided by Dr. W. Macklin (UCLA) who has published a solid phase immunoassay for PLP. For SCH, MBP or GC ELISA, Immuno II plates were coated with prepared antigen (100 μ l/well) which was incubated overnight at 4°C. The following day wells were washed in PBS and blocked with PBS + 1% serum for 1 hr at room temperature. Plates were washed again in PBS and serial dilutions of primary Ab diluted in PBS/0.1% BSA were added and incubated at room temperature for 2 hrs. Plates were washed in PBS/0.05% Tween and appropriate secondary Ab conjugated to alkaline phosphatase (1:1000 in PBS 0.1% BSA) was added. Plates were incubated at 37°C for 2 hrs, washed in PBS 0.05% Tween, and the substrate (Sigma 104 Phosphatase Substrate Tablet in 5 ml diethanolamine buffer) was added for 30 min. The reaction was terminated with 50 μ l of 1 N NaOH. The plates were read on a Dynatech ELISA plate reader.

25 Ascites production

The hybridomas chosen for treatment experiments were injected into pristane-treated BALB/c mice for ascites production. Hybridomas were also grown in RPMI-1640 media supplemented with 10% fetal bovine serum for IgM production. IgM mAbs were purified by either ammonium sulfate precipitation and gel filtration on a Sephacryl S-400 HR (Sigma) column for the initial transfer experiments, or by affinity chromatography using goat anti-mouse IgM (μ -chain specific; Jackson ImmunoResearch, West Grove, PA) coupled to

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Reacti-Gel 6X matrix (Pierce, Rockford, IL) for later transfer experiments.

Example 2: In Vitro Testing of Monoclonal Antibodies

Selection of mAbs that promote glial cell proliferation

5 The ability of the mAbs to promote proliferation of glial cells in vitro was tested. Glial cells isolated from rat brain or optic nerves were seeded in Falcon Microtest II plates at a concentration of 2×10^4 cells per well in 0.1 ml of DME. Whole serum (SCH, IFA, MBP, GC, MBP/GC, PBS or
10 PLP), purified Ig or mAb, was serially diluted and 0.1 ml aliquot was added to cells and assayed in triplicate. Three days later ^3H -thymidine was added ($1 \mu\text{Ci/ml}$) and cells were harvested after 17 hrs with an automated cell harvester (Mash II Harvester). To document identity of cells
15 proliferating (i.e., , astrocytes, progenitor glial cells, macrophages), selected cultures after exposure to ^3H -thymidine, were incubated with appropriate Ab specific for cell type followed by ABC immunoperoxidase technique. After reaction of Hanker-Yates reagent, the slides were
20 immersed in Ilford K2 nuclear emulsions, exposed for 4 days at 4°C and developed.

mAb 94.03 and 94.32 induce proliferation of mixed rat optic nerve brain cultures

One- to two-day-old rats were killed with ether. Through careful dissection, optic nerves were removed from
5 the optic nerve chiasm to the eye. Nerves were transferred to centrifuge tubes containing 2 mls of DMEM. An equal volume of 0.25% trypsin was added and incubated to 37°C in a water bath for 45 min. 0.2 ml of FCS was added to terminate trypsinization. Nerves were passed through a sterile needle
10 and syringe (gauge no. 21) and then centrifuged at 1400 rpm for 10 min. The cell count was adjusted to provide

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concentration of 5×10^5 cells/100 μ l of media in 24-well trays in DMEM + 0.5% FCS. After 12 to 16 hrs, appropriate antibodies or growth media were added as per experimental protocols.

- 5 Brains of 1-2 day old rats were removed and placed in Hank's Balanced Salt Solution with 10 mM HEPES buffer (HBSS/H), approximately 1-2 ml per brain. The brain stem, cerebellum, and midbrain was discarded whereas the forebrain was minced with a bent syringe. The tissue was further
- 10 disrupted by repeated passage through a 10 ml pipet and transferred to a 50 ml conical tube. The tissue suspension was shaken on a rotary shaker (75 rpm) for 30 min at 37°C. Trypsin was added to a final concentration of 0.125% and the suspension was shaken for an additional 60 min. Trypsin
- 15 digestion was stopped by adding FCS (10%). The cell suspension was passed sequentially through 120 and 54 μ m Nytex, centrifuged, resuspended in serum-free medium with 10% FCS, and filtered again through 54 μ m Nytex. Serum-free media was DMEM with 3.7 g/l sodium bicarbonate, 6.0 g/l
- 20 glucose, 2 mM L-glutamine, 0.1 mM nonessential amino acids, 5 μ g/ml insulin, 5 μ g/ml transferrin, 5 ng/ml selenite, 100 U/ml penicillin and 100 μ g/ml streptomycin. The cells were counted, plated onto uncoated tissue culture flasks or plates at 5×10^4 cells/cm² and cultured at 37°C in 5% CO₂.
- 25 The media was changed after 72 hrs, and every 48 hrs thereafter. On day 8 after culture initiation, the media was aspirated and replaced by SFM with various supplements (for example, antibody). For most experiments, the cells were grown for an additional 48 hrs before harvesting.
- 30 Cells were pulsed with [³H]thymidine (5 μ Ci/ml) for the final 1824 hrs of culture.

Western Blot Procedure

Antigens were denatured and solubilized by heating at 100°C in sodium dodecyl sulfate (SDS) sample buffer.

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Samples were electrophoresed on stacking and separating gels containing 4.75% and 12.0% acrylamide at 200 volts. After electrophoresis, gels and nitrocellulose membranes were equilibrated for 30 min in transfer buffer (25 mM Tris, 192 5 mM glycine, 20% methanol, pH 8.1-8.3). All steps were done at room temperature. Gels were electroblotted for either 1 hr at 100V or overnight at 30V using the Bio-Rad Mini Trans-blot apparatus. The nitrocellulose membrane was cut into strips and washed, 3X TBS (100 mM NaCl, 50 mM Tris, pH 10 7.6) with 0.03% Tween 20. Nitrocellulose strips were blocked (TBS with 3% non-fat milk and 0.03% Tween 20) for 2-4 hrs, washed 3X, and incubated with primary Ab or antisera (diluted in blocking buffer) for 4 hrs or overnight. After primary Ab incubation, strips were washed 15 3X, incubated with either biotin- or alkaline phosphate-labelled secondary Ab (diluted in blocking buffer) for 2 hrs, washed 3X, and incubated with alkaline-phosphatase labeled-streptavidin (diluted in blocking buffer) for 2 hrs if the biotin system is used. 20 Nitrocellulose strips were washed 4X (final wash in TBS without Tween 20) and incubated with substrate solution (0.165 mg/ml BCIP and 0.33 mg/ml NBT in 100 mM NaCl, 100 mM Tris, 5 mM MgCl₂, pH 9.5) until sufficient color developed (approximately 10-15 min). The reaction was stopped by 25 adding PBS with 5 mM EDTA.

Cell lines or mixed brain cultures were lysed in 1X SDS reducing sample buffer (2.3% SDS, 10% 2-ME, 0.125 M Tris, 20% glycerol) and heated to 85°C for 15 min. Nucleic acids were sheared by repeated passage of lysate through 21- 30 27-gauge needles. Lysate proteins were separated on a 12% acrylamide reducing gel, transferred to nitrocellulose membranes, and blotted with various antibodies as previously described.

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Example 3: Promotion of CNS Remyelination Using a Monoclonal Antibody

Virus

The DA strain of TMEV was obtained from Drs. J. Lehrich
5 and B. Arnason after eight passages in BHK cells. The virus
was passaged an additional four times at a multiplicity of
infection of 0.1 plaque forming units (PFU) per cell.
Cell-associated virus was released by freeze-thawing the
cultures followed by sonication. The lysate was clarified
10 by centrifugation and stored in aliquots at -70°C. All
subsequent experiments will use passage 12 virus. This
virus isolate causes white matter pathology without
destruction of anterior horn cells.

In vitro TMEV neutralization assay

15 Viral plaque assays were done as previously described
(Patick, A.K., et al., J. Neuropath. Exp. Neurol.,
50:523-537 (1991)). To assess neutralization, aliquots of
TMEV (200 PFU/ml) were incubated with various concentrations
of Ab for 1 hour at room temperature prior to plating onto
20 confluent L2 cells. As a positive control, we used serum
from susceptible mice chronically infected with TMEV. Under
the assay conditions described above, a serum dilution of
1:34,000 gave 50% neutralization, which corresponded to an
estimated 20 ng/ml of TMEV-specific Abs, assuming a total
25 serum Ig concentration of 15 mg/ml, and a TMEV-specific
fraction of 5%.

Demyelination protocol

Demyelination was induced in female SJL/J mice, ages
four to six weeks, from the Jackson Laboratory, Bar Harbor,
30 ME. Mice were inoculated intracerebrally with 2×10^5
plaque-forming units of DA virus in a volume of 10 μ l. Mice

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infected chronically with TMEV (4 to 6 months following infection) were assigned randomly to groups of treatment.

Treatment protocol and clinical disease assessment

5 Chronically infected mice were given either intraperitoneal (ip) or intravenous (iv) injections of mAb twice weekly for 4-5 weeks. At each treatment injection, mice were assessed clinically by three criteria: appearance, activity, and paralysis. A score for each criterion was given ranging
10 from 0 (no disease) to 3 (severe disease). For appearance, 1 indicated minimal change in coat, 2 indicated a moderate change (scruffy appearance), and 3 indicated a severe change (incontinence and stained coat). For activity, 1 indicated decreased spontaneous movements (minimal ataxia), 2
15 indicated moderate slowing (minimal spontaneous movements), and 3 indicated severe slowing (no spontaneous movement). For paralysis, 0.5 indicated a spastic extremity, 1 indicated a paralyzed extremity, 1.5 indicated two or more spastic extremities, 2 indicated two paralyzed extremities
20 (unable to walk), 2.5 indicated no righting response, and 3 indicated three or four paralyzed extremities (moribund). The total score for each mouse was the cumulative total from each criterion (maximum of 9). As the clinical score was an ordinal, but not a cardinal scale, the change in clinical
25 score to assess clinical disease was used. The clinical assessment data were not disclosed until after the morphological assessment of remyelination was completed.

Light and electron micrograph preparation and assessment of remyelination

30 Preparation of light and electron microscopy sections and morphological assessment of remyelination were done. Briefly, treated mice were anesthetized with pentobarbital (0.2 mg ip), exsanguinated by cardiac puncture, and killed by intracardiac perfusion with Trump's fixative (100 mM

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phosphate buffer, pH 7.2, with 4% formaldehyde and 1.5% glutaraldehyde). The entire spinal cord was removed carefully from the spinal canal, and sectioned into 1 mm transverse blocks. Every third block was post-fixed in 1% osmium tetroxide and embedded in Araldite (Polysciences, Warrington, PA). One micron sections from each block were cut and stained with p-phenylenediamine. On each section, remyelination was quantitated using a Zeiss interactive digital analysis system (ZIDAS) and camera lucida attached to a Zeiss photomicroscope (Carl Zeiss Inc., Thornwood, NY). Abnormally thin myelin sheaths relative to axonal diameter was used as the criterion for CNS remyelination. Ten spinal cord sections from each mouse were examined; this corresponded to 8-9 mm² of white matter examined per mouse. To avoid bias, slides were coded and quantitation was done without knowledge of the treatment groups.

Myelin thickness and axonal diameter measurements and quantitation of myelinated axons

Electron micrographs of normal and remyelinated axons from plastic-embedded spinal cord sections were imaged with a Hamamatsu video camera, digitized, and analyzed using an IBAS 2000 Image Analysis System (Kontron, Munich, Germany). The axonal cross-sectional area with and without the myelin sheath was measured, and equivalent circle calculations were used to determine the axonal diameter and myelin sheath thickness. For myelinated axon quantitation, the number of myelinated axons in lesions from plastic-embedded spinal cord sections were counted using the analysis system described above attached to an Axiophot microscope (Carl Zeiss, Inc.). 17 remyelinated and 15 demyelinated lesions in spinal cord sections from animals treated with mAb SCH94.03, control IgM, or buffer only were analyzed. This corresponded to 0.6 mm² of remyelinated area and 0.8 mm² of demyelinated area. The criterion for selection of a lesion

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as demyelinated was the presence of substantial demyelination with minimal repair, whereas remyelinated lesions were chosen based upon the presence of almost complete remyelination throughout the lesion.

5 Immunostaining

Rat 5.5B8 glial cells were grown on poly-D/L-lysine-coated chamber slides in Dulbecco's modified Eagle's medium (DMEM) supplemented with 1.5 g/L D-glucose, 30 nM SeO_2 , 15 nM triiodothyronine, 10 ng/ml biotin, 100 μM ZnCl₂, 50 $\mu\text{g}/\text{ml}$ gentamicin, and 10% fetal bovine serum. All staining steps were done at room temperature. For surface staining, slides were briefly rinsed with PBS, and cells were lightly fixed with 1% formaldehyde in PBS for 10 min to prevent cell detachment during subsequent staining steps.

15 For cytoplasmic staining, slides were rinsed twice in PBS and either air dried for 1 hour or incubated with 0.1% Triton X-100 in PBS for 10 min. Cells were blocked in 2% BSA for 30 min, washed, incubated with control IgM or mAb SCH94.03 (10 $\mu\text{g}/\text{ml}$ in 1% BSA) for 1 hour, and washed

20 extensively with PBS. After fixation with 4% paraformaldehyde for 15 min, slides were incubated with fluorescein-labeled goat anti-mouse IgM (Jackson Immunoresearch) for 1 hour, washed with PBS, coverslipped with 10% MOWIOL® (Hoechst) in 100 mM Tris, 25% glycerol, pH

25 8.5 with 25 $\mu\text{g}/\text{ml}$ 1,4-diazobicyclo-[2.2.2]-octane (DABCO) to prevent fading, and allowed to set overnight in the dark. For frozen tissue sections, fresh neonatal rat, adult mouse, or autopsied human cortical brain tissue was quick frozen in isopentane chilled in liquid nitrogen prior to liquid

30 nitrogen storage. Frozen sections (10 μm) were transferred onto gelatinized glass microscope slides, air dried for 4-8 hours, and stored at -70°C. Prior to immunostaining, slides were placed at room temperature overnight. The immunoperoxidase staining protocol was similar to that

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described above, using the ABC immunoperoxidase reagent (Vector Laboratories, Burlingame, CA), developed with 1.5 mg/ml Hanker-Yates reagent (p-phenylene diamine-procatechol) in 50 mM Tris, pH 7.6 with 0.034% H₂O₂, counterstained with Mayer's hematoxylin, and mounted with Permount (Fischer Scientific, Pittsburgh, PA).

Data Analysis

A modified cumulative rank sum test (O'Brien, P.C., Biometrics, 40:1079-1087 (1984)) was used to compare remyelination between treatment groups. This statistical test takes into account several numerically unrelated parameters of therapeutic effectiveness, and is used routinely for clinical trial efficacy assessment. Parallel analyses using a standard unpaired Student's t-test to compare individual parameters of remyelination gave equivalent results. Comparisons of disease severity and correlation significance were determined by a one-way analysis of variance (ANOVA). Statistical analyses were done with either the SigmaStat (Jandel Scientific, San Rafael, CA) or EXCEL (Microsoft Corporation, Redmond, WA) software programs. Calculated values were considered significant when $p < 0.05$.

Equivalents

Those skilled in the art will recognize, or be able to ascertain, using no more than routine experimentation, many equivalents to the specific embodiments of the invention described herein. Such equivalents are intended to be encompassed by the following claims:

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SEQUENCE LISTING

(1) GENERAL INFORMATION:

- (i) APPLICANT: Mayo Foundation for Medical Education Research
- (ii) TITLE OF INVENTION: MONOCLONAL ANTIBODIES WHICH PROMOTE
CENTRAL NERVOUS SYSTEM REMYELINATION
- (iii) NUMBER OF SEQUENCES: 11
- (iv) CORRESPONDENCE ADDRESS:
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 - (F) ZIP: 02173
- (v) COMPUTER READABLE FORM:
 - (A) MEDIUM TYPE: Floppy disk
 - (B) COMPUTER: IBM PC compatible
 - (C) OPERATING SYSTEM: PC-DOS/MS-DOS
 - (D) SOFTWARE: PatentIn Release #1.0, Version #1.25
- (vi) CURRENT APPLICATION DATA:
 - (A) APPLICATION NUMBER:
 - (B) FILING DATE:
 - (C) CLASSIFICATION:
- (vii) PRIOR APPLICATION DATA:
 - (A) APPLICATION NUMBER: U.S. 08/236,520
 - (B) FILING DATE: April 29, 1994
- (viii) ATTORNEY/AGENT INFORMATION:
 - (A) NAME: Granahan, Patricia
 - (B) REGISTRATION NUMBER: 27,227
 - (C) REFERENCE/DOCKET NUMBER: MMV92-01 PCT
- (ix) TELECOMMUNICATION INFORMATION:
 - (A) TELEPHONE: 617-861-6240
 - (B) TELEFAX: 617-861-9540

(2) INFORMATION FOR SEQ ID NO:1:

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 393 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: double
 - (D) TOPOLOGY: linear
- (ix) FEATURE:
 - (A) NAME/KEY: CDS
 - (B) LOCATION: 1..393

-36-

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

ATG	ATG	TCC	TCT	GCT	CAG	TTC	CTT	GGT	CTC	CTG	TTG	CTC	TGT	TTT	CAA	48
Met	Met	Ser	Ser	Ala	Gln	Phe	Leu	Gly	Leu	Leu	Leu	Leu	Cys	Phe	Gln	
1				5				10						15		
GGT	ACC	AGA	TGT	GAT	ATC	CAG	ATG	ACA	CAG	ACT	ACA	TCC	TCC	CTG	TCT	96
Gly	Thr	Arg	Cys	Asp	Ile	Gln	Met	Thr	Gln	Thr	Thr	Ser	Ser	Leu	Ser	
			20					25					30			
GCC	TCT	CTG	GGA	GAC	AGA	GTC	ACC	ATC	AGT	TGC	AGG	GCA	AGT	CAG	GAC	144
Ala	Ser	Leu	Gly	Asp	Arg	Val	Thr	Ile	Ser	Cys	Arg	Ala	Ser	Gln	Asp	
		35					40					45				
ATT	AGC	AAT	TAT	TTA	AAC	TGG	TAT	CAG	CAG	AAA	CCA	GAT	GGA	ACT	GTT	192
Ile	Ser	Asn	Tyr	Leu	Asn	Trp	Tyr	Gln	Gln	Lys	Pro	Asp	Gly	Thr	Val	
	50					55					60					
AAA	CTC	CTG	ATC	TAC	TAC	ACA	TCA	AGA	TTA	CAC	TCA	GGA	GTC	CCA	TCA	240
Lys	Leu	Leu	Ile	Tyr	Tyr	Thr	Ser	Arg	Leu	His	Ser	Gly	Val	Pro	Ser	
	65				70					75					80	
AGG	TTC	AGT	GGC	AGT	GGG	TCT	GGA	ACA	GAT	TAT	TCT	CTC	ACC	ATT	AGC	288
Arg	Phe	Ser	Gly	Ser	Gly	Ser	Gly	Thr	Asp	Tyr	Ser	Leu	Thr	Ile	Ser	
				85					90					95		
AAC	CTG	GAG	CAA	GAA	GAT	ATT	GCC	ACT	TAC	TTT	TGC	CAA	CAG	GGT	AAT	336
Asn	Leu	Glu	Gln	Glu	Asp	Ile	Ala	Thr	Tyr	Phe	Cys	Gln	Gln	Gly	Asn	
			100					105					110			
ACG	CTT	CCG	TGG	ACG	TTC	GGT	GGA	GGC	ACC	AAG	CTG	GAA	ATC	AAA	CGG	384
Thr	Leu	Pro	Trp	Thr	Phe	Gly	Gly	Gly	Thr	Lys	Leu	Glu	Ile	Lys	Arg	
		115					120					125				
GCT	GAT	GCT														393
Ala	Asp	Ala														
		130														

(2) INFORMATION FOR SEQ ID NO:2:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 131 amino acids
 - (B) TYPE: amino acid
 - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Met	Met	Ser	Ser	Ala	Gln	Phe	Leu	Gly	Leu	Leu	Leu	Leu	Cys	Phe	Gln
1				5				10						15	
Gly	Thr	Arg	Cys	Asp	Ile	Gln	Met	Thr	Gln	Thr	Thr	Ser	Ser	Leu	Ser
			20					25					30		
Ala	Ser	Leu	Gly	Asp	Arg	Val	Thr	Ile	Ser	Cys	Arg	Ala	Ser	Gln	Asp
		35					40					45			
Ile	Ser	Asn	Tyr	Leu	Asn	Trp	Tyr	Gln	Gln	Lys	Pro	Asp	Gly	Thr	Val
	50					55					60				

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Lys Leu Leu Ile Tyr Tyr Thr Ser Arg Leu His Ser Gly Val Pro Ser
 65 70 75 80
 Arg Phe Ser Gly Ser Gly Ser Gly Thr Asp Tyr Ser Leu Thr Ile Ser
 85 90 95
 Asn Leu Glu Gln Glu Asp Ile Ala Thr Tyr Phe Cys Gln Gln Gly Asn
 100 105 110
 Thr Leu Pro Trp Thr Phe Gly Gly Gly Thr Lys Leu Glu Ile Lys Arg
 115 120 125
 Ala Asp Ala
 130

(2) INFORMATION FOR SEQ ID NO:3:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 324 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: double
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

GATATCCAGA TGACACAGAC TACATCCTCC CTGTCTGCCT CTCTGGGAGA CAGAGTCACC	60
ATCAGTTGCA GGGCAAGTCA GGACATTAGC AATTATTTAA ACTGGTATCA GCAGAAACCA	120
GATGGAACTG TTAAACTCCT GATCTACTAC ACATCAAGAT TACTCTCAGG AGTCCCATCA	180
AGGTTCACTG GCAGTGGGTC TGGAACAGAT TATTCTCTCA CCATTAGCAA CCTGGAGCAA	240
GAAGATATTG CCACTTACTT TTGCCAACAG GGTAATACGC TTCCTCCGAC GTTCGGTGGA	300
GGCACCAAGC TGGAATCAA ACGG	324

(2) INFORMATION FOR SEQ ID NO:4:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 285 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: double
 - (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

GATATCCAGA TGACACAGAC TACATCCTCC CTGTCTGCCT CTCTGGGAGA CAGAGTCACC	60
ATCAGTTGCA GGGCAAGTCA GGACATTAGC AATTATTTAA ACTGGTATCA GCAGAAACCA	120
GATGGAACTG TTAAACTCCT GATCTACTAC ACATCAAGAT TACTCTCAGG AGTCCCATCA	180
AGGTTCACTG GCAGTGGGTC TGGAACAGAT TATTCTCTCA CCATTAGCAA CCTGGAGCAA	240
GAAGATATTG CCACTTACTT TTGCCAACAG GGTAATACGC TTCCT	285

-38-

(2) INFORMATION FOR SEQ ID NO:5:

- (i) SEQUENCE CHARACTERISTICS:
 (A) LENGTH: 39 base pairs
 (B) TYPE: nucleic acid
 (C) STRANDEDNESS: double
 (D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

TGGACGTTTCG GTGGAGGCAC CAAGCTGGAA ATCAAACGT

39

(2) INFORMATION FOR SEQ ID NO:6:

- (i) SEQUENCE CHARACTERISTICS:
 (A) LENGTH: 429 base pairs
 (B) TYPE: nucleic acid
 (C) STRANDEDNESS: double
 (D) TOPOLOGY: linear

(ix) FEATURE:

- (A) NAME/KEY: CDS
 (B) LOCATION: 1..429

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

ATG GGA TGG AGC TGT ATC ATC CTC TTT TTG GTA GCA GCA GCT ACA GGT	48
Met Gly Trp Ser Cys Ile Ile Leu Phe Leu Val Ala Ala Ala Thr Gly	
1 5 10 15	
GTC CAC TCC CAG GTC CAA CTG CAG CAG CCT GGG ACT GAA CTG GTG AAG	96
Val His Ser Gln Val Gln Leu Gln Gln Pro Gly Thr Glu Leu Val Lys	
20 25 30	
CCT GGG GCT TCA GTG AAG CTG TCC TGC AAG GCT TCT GGC TAC ACC TTC	144
Pro Gly Ala Ser Val Lys Leu Ser Cys Lys Ala Ser Gly Tyr Thr Phe	
35 40 45	
ACC AGC TAC TGG ATG CAC TGG GTG AAG CAG AGG CCT GGA CAA GGC CTT	192
Thr Ser Tyr Trp Met His Trp Val Lys Gln Arg Pro Gly Gln Gly Leu	
50 55 60	
GAG TGG ATT GGA AAT ATT AAT CCT AGC AAT GGT GGT ACT AAC TAC AAT	240
Glu Trp Ile Gly Asn Ile Asn Pro Ser Asn Gly Gly Thr Asn Tyr Asn	
65 70 75 80	
GAG AAG TTC AAG AGC AAG GCC ACA CTG ACT GTA GAC AAA TCC TCC AGC	288
Glu Lys Phe Lys Ser Lys Ala Thr Leu Thr Val Asp Lys Ser Ser Ser	
85 90 95	
ACA GCC TAC ATG CAG CTC AGC AGC CTG ACA TCT GAG GAC TCT GCG GTC	336
Thr Ala Tyr Met Gln Leu Ser Ser Leu Thr Ser Glu Asp Ser Ala Val	
100 105 110	
TAT TAT TAT GCA AGA CGG GCC CCT TAC TAC GGT AGT AGG AAC TTT GAC	384
Tyr Tyr Tyr Ala Arg Arg Ala Pro Tyr Tyr Gly Ser Arg Asn Phe Asp	
115 120 125	
TAC TGG GGC CAA GGC ACC ACT CTC ACA GTC TCC TCA GAG AGT CAG	429
Tyr Trp Gly Gln Gly Thr Thr Leu Thr Val Ser Ser Glu Ser Gln	
130 135 140	

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(2) INFORMATION FOR SEQ ID NO:7:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 143 amino acids
 (B) TYPE: amino acid
 (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

```

Met Gly Trp Ser Cys Ile Ile Leu Phe Leu Val Ala Ala Ala Thr Gly
 1           5           10           15
Val His Ser Gln Val Gln Leu Gln Gln Pro Gly Thr Glu Leu Val Lys
          20           25           30
Pro Gly Ala Ser Val Lys Leu Ser Cys Lys Ala Ser Gly Tyr Thr Phe
          35           40           45
Thr Ser Tyr Trp Met His Trp Val Lys Gln Arg Pro Gly Gln Gly Leu
          50           55           60
Glu Trp Ile Gly Asn Ile Asn Pro Ser Asn Gly Gly Thr Asn Tyr Asn
 65           70           75           80
Glu Lys Phe Lys Ser Lys Ala Thr Leu Thr Val Asp Lys Ser Ser Ser
          85           90           95
Thr Ala Tyr Met Gln Leu Ser Ser Leu Thr Ser Glu Asp Ser Ala Val
          100          105          110
Tyr Tyr Tyr Ala Arg Arg Ala Pro Tyr Tyr Gly Ser Arg Asn Phe Asp
          115          120          125
Tyr Trp Gly Gln Gly Thr Thr Leu Thr Val Ser Ser Glu Ser Gln
          130          135          140

```

(2) INFORMATION FOR SEQ ID NO:8:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 366 base pairs
 (B) TYPE: nucleic acid
 (C) STRANDEDNESS: double
 (D) TOPOLOGY: linear

(ix) FEATURE:

- (A) NAME/KEY: CDS
 (B) LOCATION: 1..366

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:8:

```

CAG GTC CAA CTG CAG CAG CCT GGG ACT GAA CTG GTG AAG CCT GGG GCT      48
Gln Val Gln Leu Gln Gln Pro Gly Thr Glu Leu Val Lys Pro Gly Ala
 1           5           10           15
TCA GTG AAG CTG TCC TGC AAG GCT TCT GGC TAC ACC TTC ACC AGC TAC      96
Ser Val Lys Leu Ser Cys Lys Ala Ser Gly Tyr Thr Phe Thr Ser Tyr
          20           25           30

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TGG ATG CAC TGG GTG AAG CAG AGG CCT GGA CAA GGC CTT GAG TGG ATT	144
Trp Met His Trp Val Lys Gln Arg Pro Gly Gln Gly Leu Glu Trp Ile	
35 40 45	
GGA AAT ATT AAT CCT AGC AAT GGT GGT ACT AAC TAC AAT GAG AAG TTC	192
Gly Asn Ile Asn Pro Ser Asn Gly Gly Thr Asn Tyr Asn Glu Lys Phe	
50 55 60	
AAG AGC AAG GCC ACA CTG ACT GTA GAC AAA TCC TCC AGC ACA GCC TAC	240
Lys Ser Lys Ala Thr Leu Thr Val Asp Lys Ser Ser Ser Thr Ala Tyr	
65 70 75 80	
ATG CAG CTC AGC AGC CTG ACA TCT GAG GAC TCT GCG GTC TAT TAT TAT	288
Met Gln Leu Ser Ser Leu Thr Ser Glu Asp Ser Ala Val Tyr Tyr Tyr	
85 90 95	
GCA AGA GAT TAC TAC GGT AGT AGC TGG GGG TAC TAC TTT GAC TAC TGG	336
Ala Arg Asp Tyr Tyr Gly Ser Ser Trp Gly Tyr Tyr Phe Asp Tyr Trp	
100 105 110	
GGC CAA GGC ACC ACT CTC ACA GTC TCC TCA	366
Gly Gln Gly Thr Thr Leu Thr Val Ser Ser	
115 120	

(2) INFORMATION FOR SEQ ID NO:9:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 122 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:9:

Gln Val Gln Leu Gln Gln Pro Gly Thr Glu Leu Val Lys Pro Gly Ala	
1 5 10 15	
Ser Val Lys Leu Ser Cys Lys Ala Ser Gly Tyr Thr Phe Thr Ser Tyr	
20 25 30	
Trp Met His Trp Val Lys Gln Arg Pro Gly Gln Gly Leu Glu Trp Ile	
35 40 45	
Gly Asn Ile Asn Pro Ser Asn Gly Gly Thr Asn Tyr Asn Glu Lys Phe	
50 55 60	
Lys Ser Lys Ala Thr Leu Thr Val Asp Lys Ser Ser Ser Thr Ala Tyr	
65 70 75 80	
Met Gln Leu Ser Ser Leu Thr Ser Glu Asp Ser Ala Val Tyr Tyr Tyr	
85 90 95	
Ala Arg Asp Tyr Tyr Gly Ser Ser Trp Gly Tyr Tyr Phe Asp Tyr Trp	
100 105 110	
Gly Gln Gly Thr Thr Leu Thr Val Ser Ser	
115 120	

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(2) INFORMATION FOR SEQ ID NO:10:

- (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 351 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: double
(D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:10:

ATGGGATGGA GCTGTATCAT CCTCTTTTGT GTAGCAGCAG CTACAGGTGT CCACTCCCAG	60
GTCCAACTGC AGCAGCCTGG GACTGAACTG GTGAAGCCTG GGGCTTCAGT GAAGCTGTCC	120
TGCAAGGCTT CTGGCTACAC CTTCAACCAGC TACTGGATGC ACTGGGTGAA GCAGAGGCCT	180
GGACAAGGCC TTGAGTGGAT TGGAAATATT AATCCTAGCA ATGGTGGTAC TAACTACAAT	240
GAGAAGTTCA AGAGCAAGGC CACTCTGACT GTAGACAAAT CCTCCAGCAC AGCCTACATG	300
CAGCTCAGCA GCCTGACATC TGAGGACTCT GCGGTCTATT ATTATGCAAG A	351

(2) INFORMATION FOR SEQ ID NO:11:

- (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 45 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: double
(D) TOPOLOGY: linear

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:11:

TACTTTGACT ACTGGGGCCA AGGCACCACT CTCACAGTCT CCTCA	45
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CLAIMS

What is claimed is:

1. A method of stimulating remyelination of central nervous system axons in a mammal comprising
5 administering to the mammal an effective amount of a monoclonal antibody produced by the hybridoma having the ATCC Accession No. CRL 11627.
2. The method of Claim 1 wherein the method of administration is intravenous administration.
- 10 3. The method of Claim 1 wherein the method of administration is intraperitoneal administration.
4. The method of Claim 1 wherein said amount of monoclonal antibody administered is between from about 0.5 mg/kg to about 400 mg/kg.
- 15 5. A method of stimulating the proliferation of glial cells in central nervous system axons in a mammal comprising administering to the mammal an effective amount of a monoclonal antibody produced by the hybridoma having the ATCC Accession No. CRL 11627.
- 20 6. The method of Claim 5 wherein the method of administration is intravenous administration.
7. The method of Claim 5 wherein the method of administration is intraperitoneal administration.

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8. The method of Claim 5 wherein said amount of monoclonal antibody administered is between from about 0.5 mg/kg to about 400 mg/kg.
9. A method of treating a demyelinating disease of the central nervous system in a mammal comprising administering to said mammal an effective amount of a monoclonal antibody produced by the hybridoma having the ATCC Accession No. CRL 11627 to promote remyelination of central nervous system axons of said mammal.
10. The method of Claim 9 wherein said mammal is a human being having multiple sclerosis, or a human or domestic animal with a viral demyelinating disease, or a post-neural disease of the central nervous system.
11. The method of Claim 9 wherein the method of administration is intravenous administration.
12. The method of Claim 9 wherein the method of administration is intraperitoneal administration.
13. The method of Claim 9 wherein said amount of monoclonal antibody administered is between from about 0.5 mg/kg to about 400 mg/kg.
14. The method of Claim 9 wherein said mammal is a mouse infected with Strain DA of Theiler's murine encephalomyelitis virus.
15. A hybridoma comprising hybridoma ATCC accession No. CRL 11627 that produces a monoclonal antibody capable of stimulating remyelination of central nervous system axons.

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16. An in vitro method of producing glial cells comprising:
- a) culturing glial cells under conditions sufficient for cell proliferation, thereby producing a glial cell culture;
 - 5 b) introducing into the glial cell culture an effective amount of a monoclonal antibody produced by the hybridoma having the ATCC Accession No. CRL 11627, thereby producing a monoclonal antibody-treated glial cell culture;
 - 10 c) maintaining the culture of step b) under conditions sufficient for proliferation of monoclonal antibody-treated cells; and
 - d) harvesting the cells from culture, thereby obtaining glial cells.
- 15 17. Glial cells obtained by the method of Claim 16.
18. An in vitro method of stimulating the proliferation of glial cells from mixed cell culture comprising:
- a) culturing a mixed cell culture containing glial cells under conditions sufficient for cell proliferation;
 - 20 b) introducing into the mixed culture an effective amount of a monoclonal antibody produced by the hybridoma having the ATCC Accession No. CRL 11627, thereby producing a monoclonal antibody-treated mixed culture;
 - 25 c) maintaining the culture of step b) under conditions sufficient for proliferation of monoclonal antibody-treated cells, thereby resulting in the proliferation of glial cells in the mixed culture; and
 - 30 d) harvesting the glial cells from the mixed culture.

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19. The method of Claim 18 wherein the mixed culture is obtained from rat optic nerve.
20. The method of Claim 18 wherein the mixed culture is obtained from rat brain.
- 5 21. Glial cells obtained by the method of Claim 18.
22. A method of stimulating remyelination of central nervous system axons in a mammal comprising;
- 10 a) culturing glial cells under conditions sufficient for cell proliferation, thereby producing a glial cell culture;
- b) introducing into the glial cell culture an effective amount of a monoclonal antibody produced by the hybridoma having the ATCC Accession No. CRL 11627, thereby producing a monoclonal antibody-
- 15 treated glial cell culture;
- c) maintaining the culture of step b) under conditions sufficient for proliferation of monoclonal antibody-treated cells;
- 20 d) harvesting the monoclonal antibody-treated cells from culture, thereby obtaining glial cells; and
- e) introducing the glial cells obtained in step d) into the central nervous system of the mammal, thereby stimulating remyelination of central nervous system axons.
- 25 23. A monoclonal antibody producible from hybridoma according to Claim 15.
24. A monoclonal antibody according to Claim 23 for use in therapy.

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25. Use of monoclonal antibody according to Claim 23 for the manufacture of a medicament for stimulating remyelination of central nervous system axons.
- 5 26. Use of a monoclonal antibody according to Claim 23 for the manufacture of a medicament for stimulating the proliferation of glial cells in central nervous system axons.
- 10 27. Use of a monoclonal antibody according to Claim 23 for the manufacture of a medicament for treating a demyelinating disease of the central nervous system e.g. multiple sclerosis, a viral demyelinating disease, or a post-neural disease of the central nervous system.
- 15 28. Use according to Claim 27, wherein the medicament is for treating a mouse infected with Strain DA of Theiler's murine encephalomyelitis virus.
29. Use according to any one of Claims 25, 26 and 27, wherein the method of administration is intravenous administration, or intraperitoneal administration.
- 20 30. Use according to any one of Claims 25 to 28, wherein said amount of monoclonal antibody administered is from about 0.5 mg/kg to about 400 mg/kg.
31. A method of preparing glial cells for stimulating remyelination of central nervous system axons in a mammal comprising;
25 a) culturing glial cells under conditions sufficient for cell proliferation, thereby producing a glial cell culture;
b) introducing into the glial cell culture an effective amount of a monoclonal antibody produced

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by the hybridoma having the ATCC Accession No. CRL 11627, thereby producing a monoclonal antibody-treated glial cell culture;

- 5 c) maintaining the culture of step b) under conditions sufficient for proliferation of monoclonal antibody-treated cells from culture, thereby obtaining glial cells.

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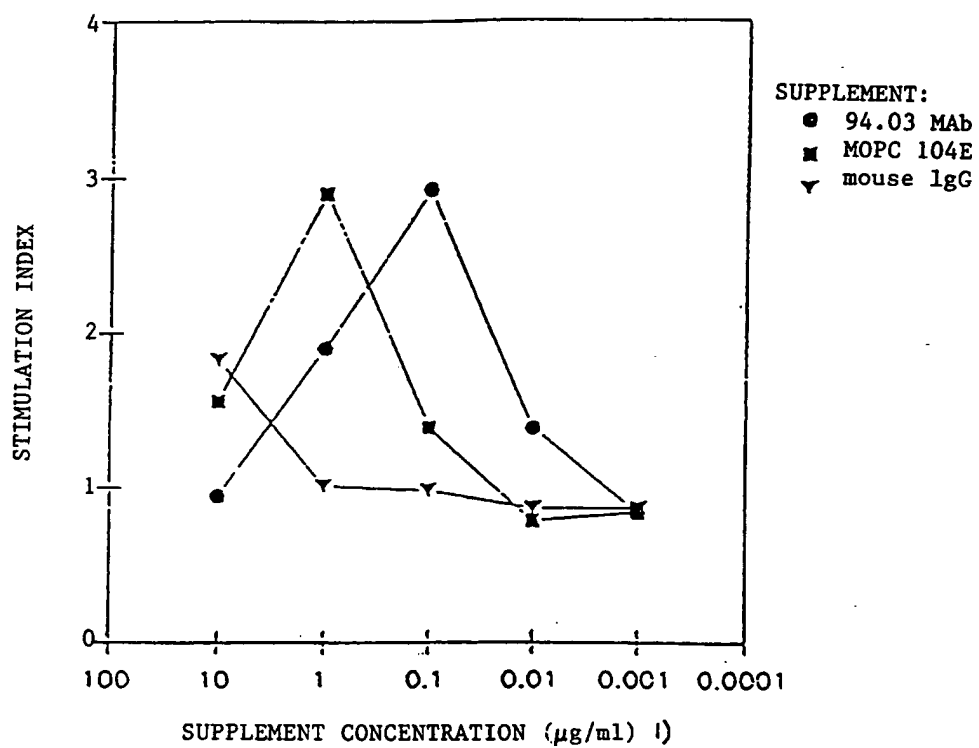


Figure 1

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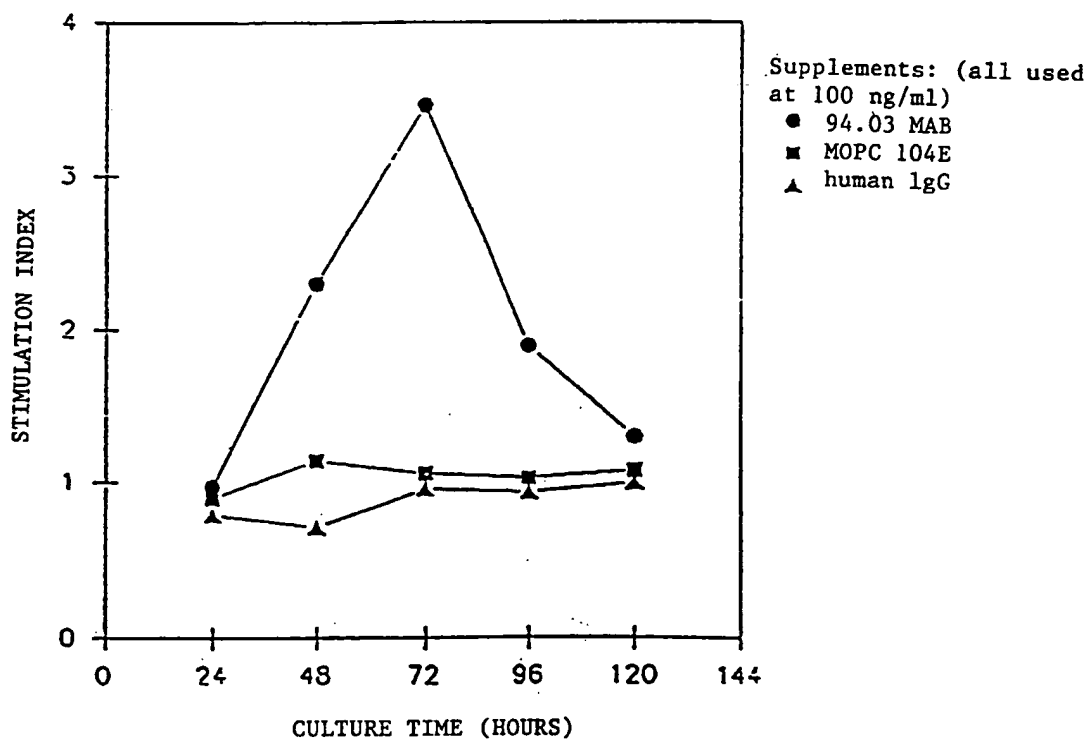


Figure 2

SUBSTITUTE SHEET (RULE 26)

FIG. 3A

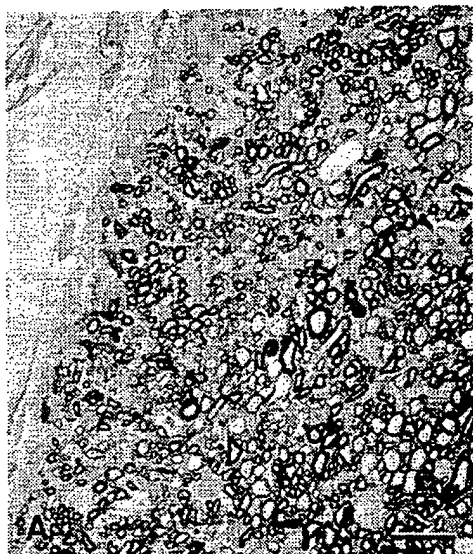


FIG. 3B

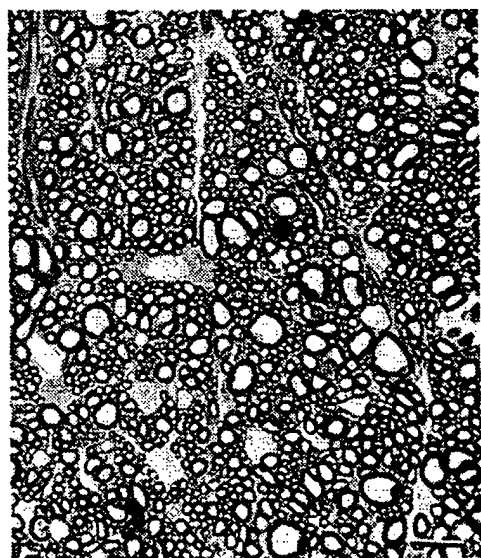
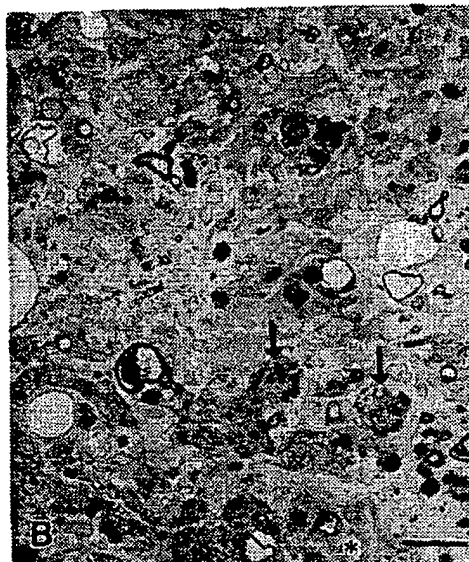


FIG. 3C

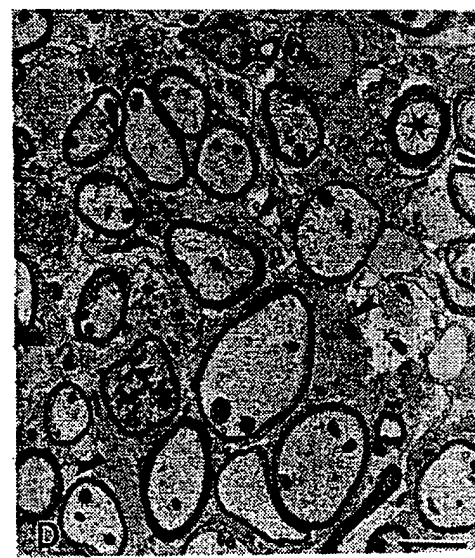


FIG. 3D

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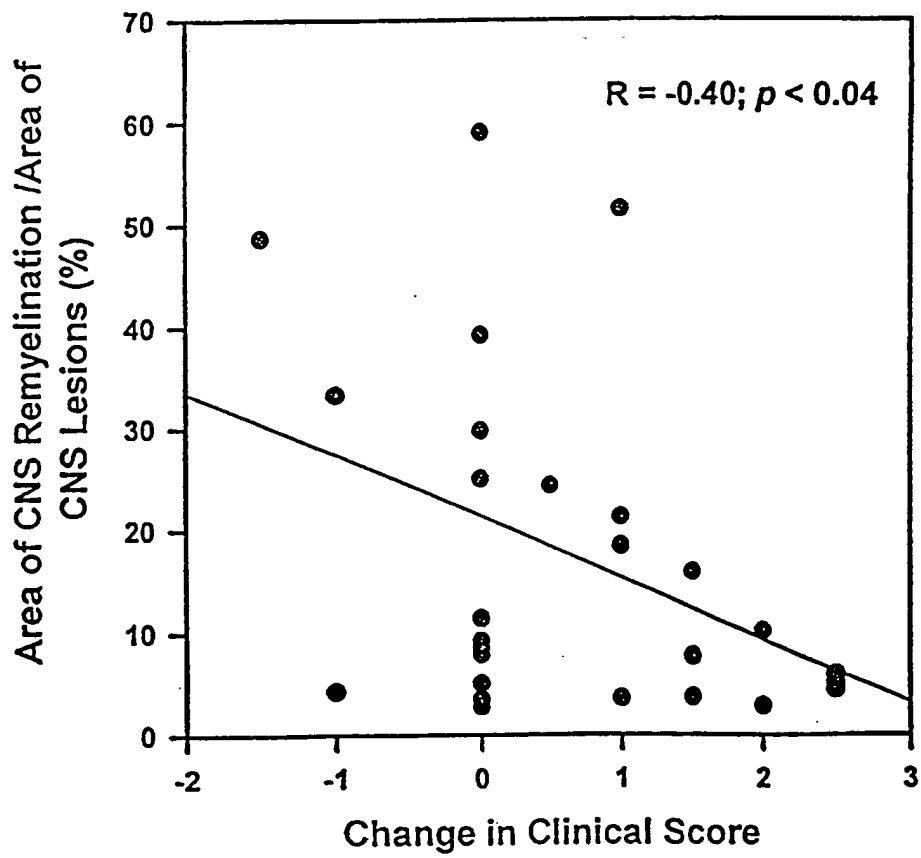


Figure 4

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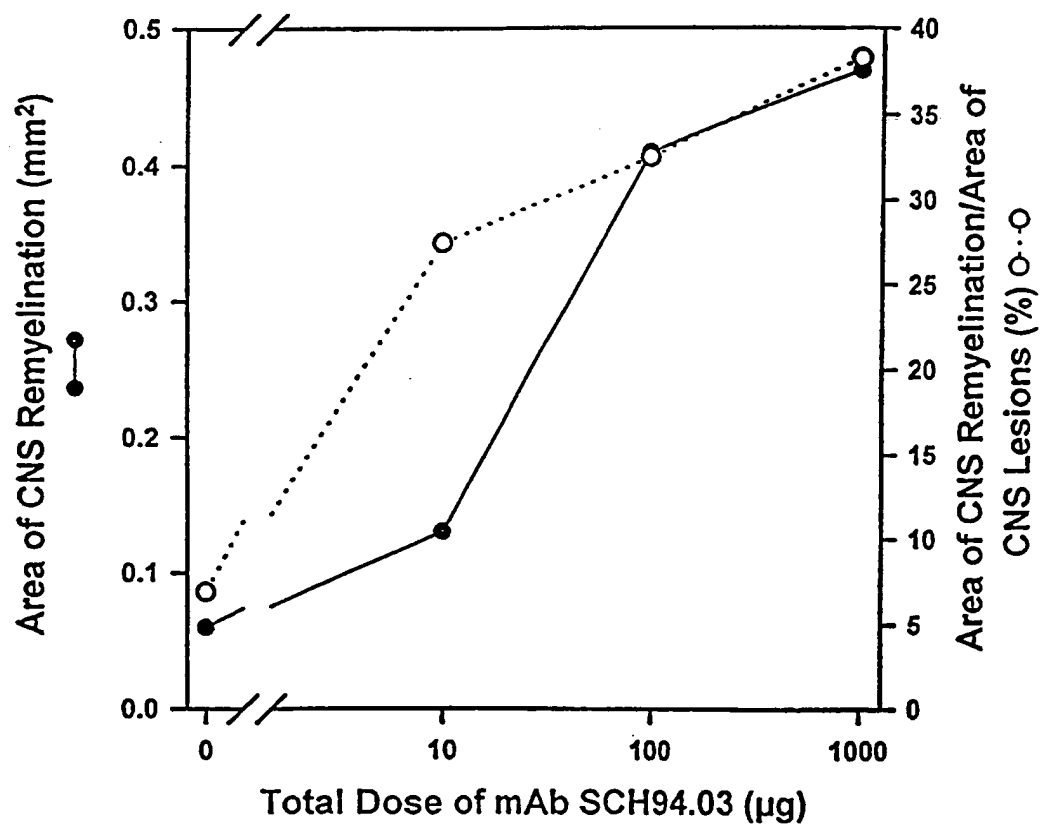


Figure 5

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FIG. 6

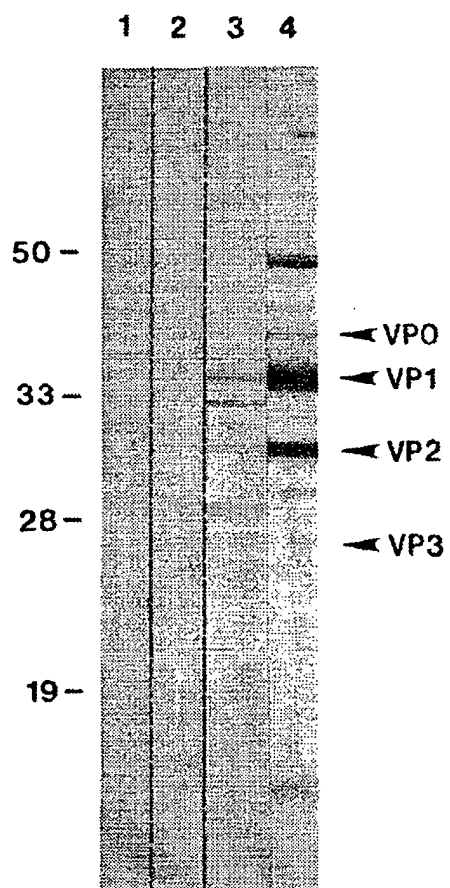


FIG. 7A



FIG. 7B



FIG. 7C

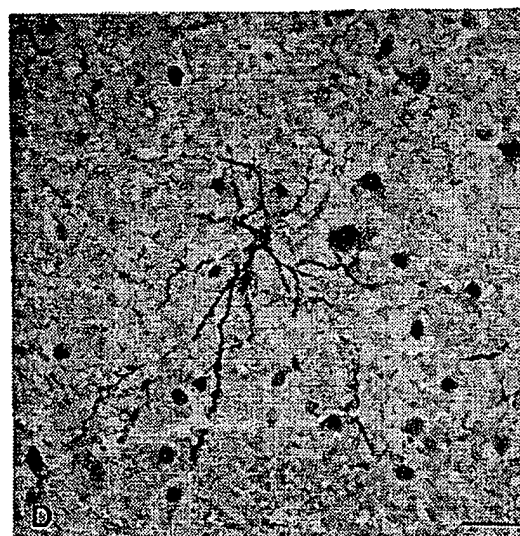


FIG. 7D

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Fig. 8A

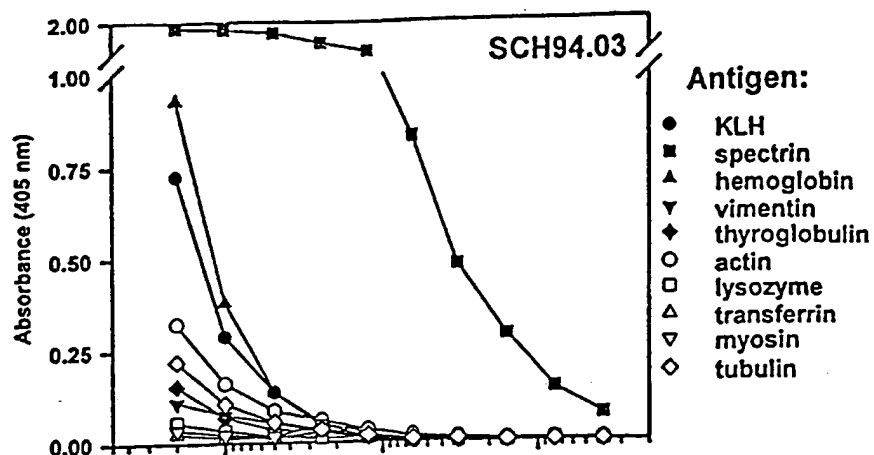


Fig. 8B

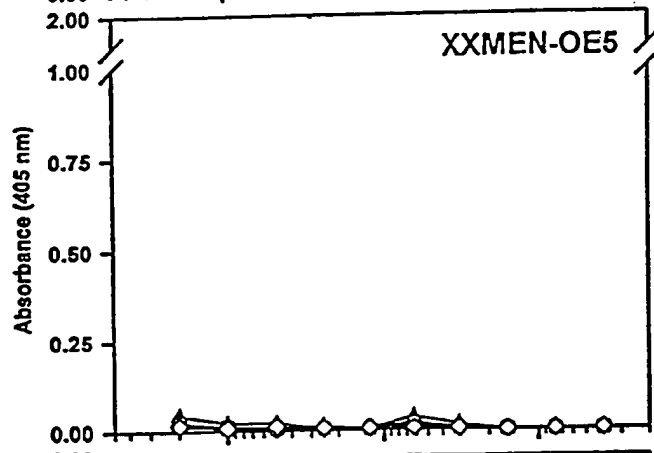
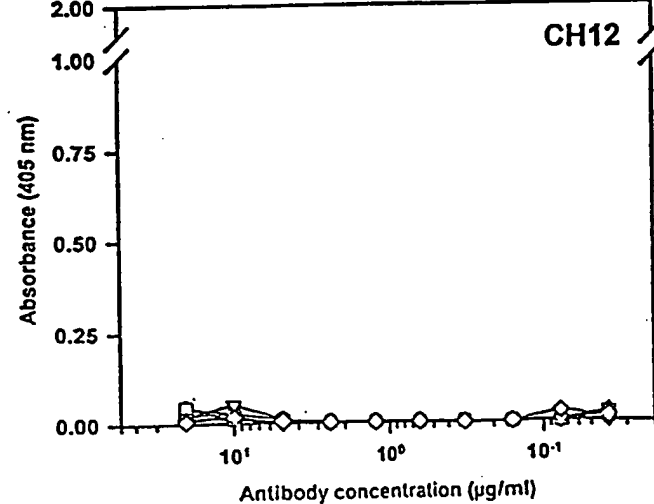


Fig. 8C



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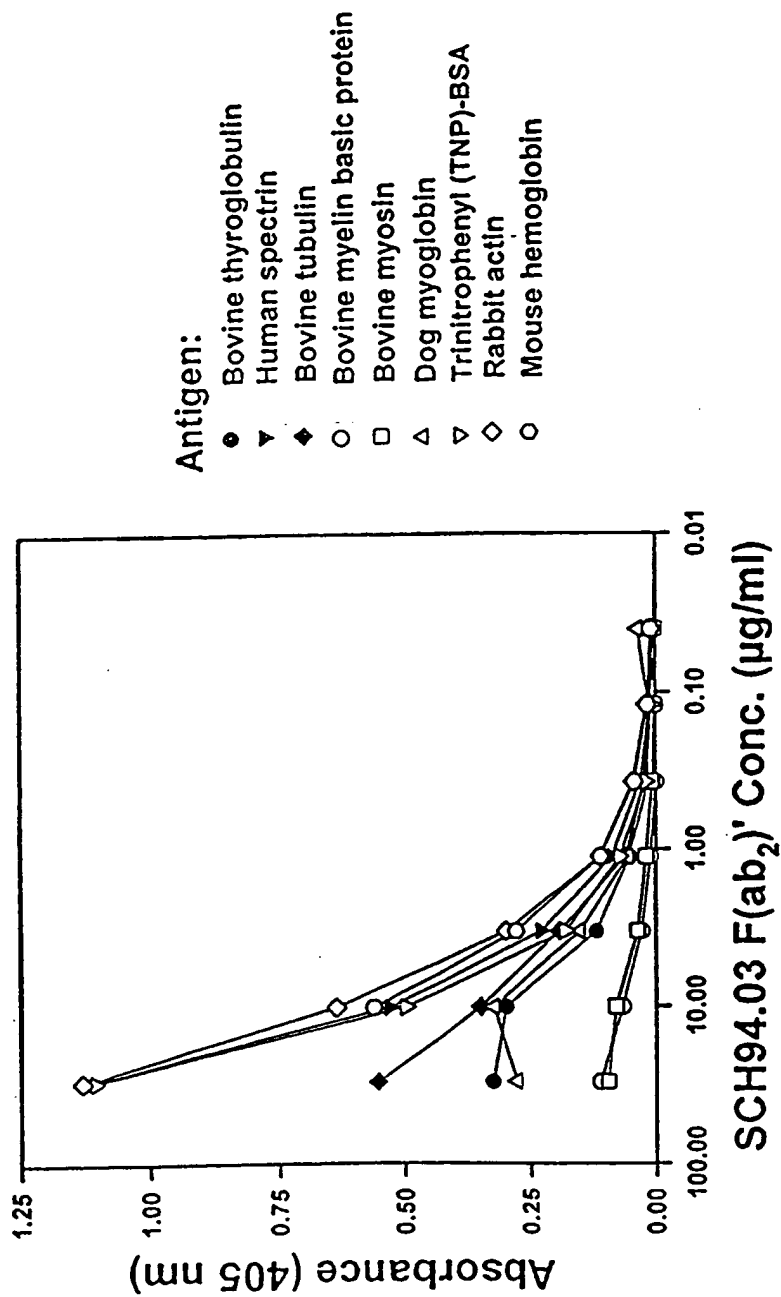


Figure 9

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Fig. 10A

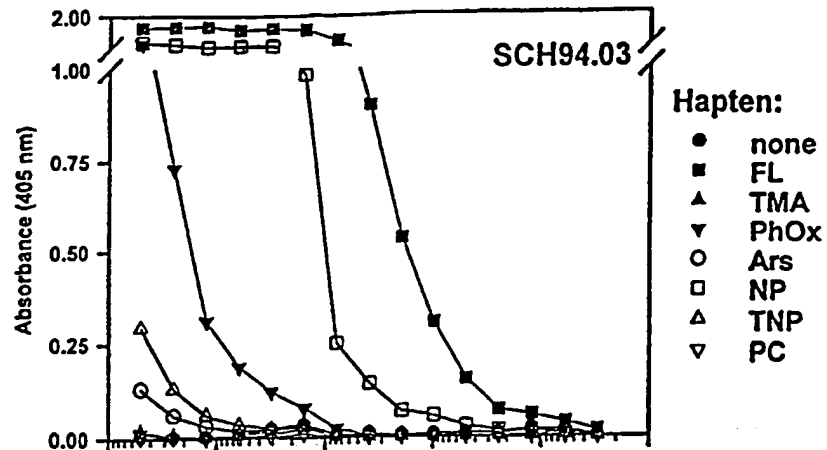


Fig. 10B

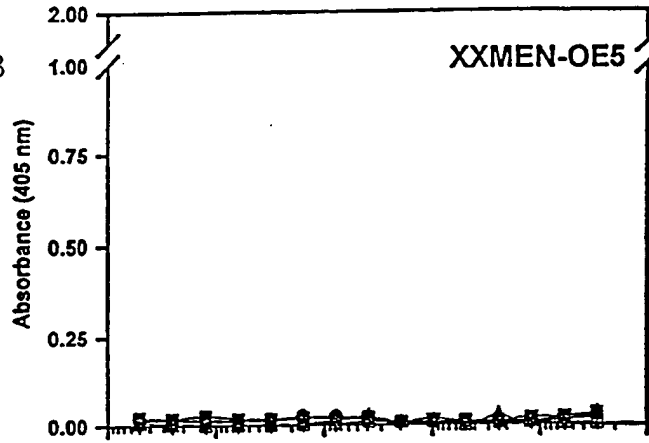
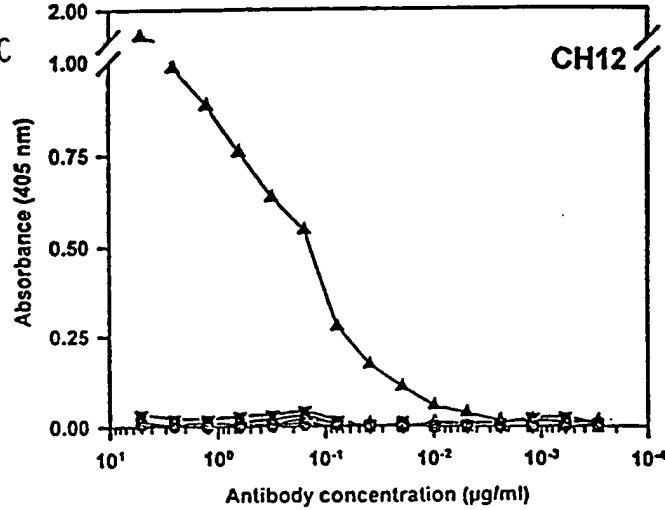


Fig. 10C



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SCH94.03	CH12	M	G	W	S	C	I	I	L	F	L	V	A	A	A	T	G	V	H	S	Q	V	Q	L	Q	Q	P	G	G
germline V _H 23		ATG	GGA	TGG	AGC	TGT	ATC	ATC	CTC	TTT	TTG	GTA	GCA	GCT	ACA	GGT	GTC	CAC	TCC	CAG	GTC	CAA	CTG	CAG	CAG	CCT	GGG		
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	Leader region																										
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SCH94.03	M	M	S	S	A	Q	F	L	G	L	L	L	L	C	F	Q	G	T	R	C	D	I	Q	M	T	Q	T
CH12	ATG	ATG	TCC	TCT	GCT	CAG	TTC	GTT	GCT	CTC	CTG	TTG	CTC	TGT	TTT	CAA	GST	ACC	AGA	TGT	GAT	ATC	CAG	ATG	ACA	CAG	ACT
germline Vx10																											
SCH94.03	T	S	S	L	S	A	S	L	G	D	R	V	T	I	S	C	R	A	S	Q	D	I	S	N	Y	L	N
CH12	ACA	TCC	TCC	CTG	TCT	GCC	TCT	CTG	GGA	GAC	AGA	GTC	ACC	ATC	AGT	TGC	AGG	GCA	AGT	CAG	GAC	ATT	AGC	AAT	TAT	TTA	AAC
germline Vx10																											
SCH94.03	W	Y	Q	Q	K	P	D	G	T	V	K	L	L	L	I	Y	Y	T	S	R	L	H	S	G	V	P	S
CH12	TGG	TAT	CAG	CAG	AAA	CCA	GAT	GGA	ACT	GTT	AAA	CTC	CTG	ATC	TAC	TAC	ACA	TCA	AGA	TTA	CAC	TCA	GGA	GTC	CCA	TCA	AGG
germline Vx10																											
SCH94.03	F	S	G	S	G	S	G	T	D	Y	S	L	T	I	S	N	L	E	Q	E	D	I	A	T	Y	F	C
CH12	TTC	AGT	GGC	AGT	GGG	TCT	GGA	ACA	GAT	TAT	TCT	CTC	ACC	ATT	AGC	AAC	CTG	GAG	CAA	GAA	GAT	ATT	GCC	ACT	TAC	TTT	TGC
germline Vx10																											
SCH94.03	Q	Q	G	N	T	L	P	W	T	F	G	G	G	T	K	L	E	I	K	R	A	D	A				
CH12	CNA	CAG	GGT	ANT	ACG	CTT	CCG	TGG	ACG	TTC	GGT	GGA	GGC	ACC	AAG	CTG	GAA	ATC	AAA	CGG	GCT	GAT	GCT				
germline Vx10																											
SCH94.03																											
CH12																											
germline Vx10																											

Figure 11B

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 95/05262

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 C12N15/13 A61K39/395 C07K16/18 C12N5/20 C12N5/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 C07K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DATABASE MEDLINE FILE SERVER STN KARLSRUHE ABSTRACT NO.91374165, PATICK ET AL 'PERSISTENCE OF THEILER'S VIRUS INFECTION FOLLOWING PROMOTION OF CENTRAL NERVOUS SYSTEM REMYELINATION' cited in the application	23-30
A	& J NEUROPATHOL EXP NEUROL, (1991 SEP) 50 (5) 523-37 see abstract --- -/--	1-22, 31



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

18 August 1995

Date of mailing of the international search report

28.08.95

Name and mailing address of the ISA

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Fax: (+31-70) 340-3016

Authorized officer

Sitch, W

INTERNATIONAL SEARCH REPORT

 Internat Application No
 PCT/US 95/05262

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DATABASE MEDLINE FILE SERVER STN KARLSRUHE ABSTRACT NO.90146187, RODRIGUEZ ET AL 'IMMUNOGLOBULINS PROMOTE REMYELINATION IN THE CENTRAL NERVOUS SYSTEM'	23-30
A	& ANN NEUROL, (1990 JAN) 27 (1) 12-7 see abstract ---	1-22,31
X	DATABASE MEDLINE FILE SERVER STN KARLSRUHE ABSTRACT NO.87085707, RODRIGUEZ ET AL 'REMYELINATION BY OLIGODENDROCYTES STIMULATED BY ANTISERUM TO SPINAL CORD'	23-30
A	& J NEUROPATHOL EXP NEUROL, (1987 JAN) 46 (1) 84-95 see abstract ---	1-22,31
X	DATABASE MEDLINE FILE SERVER STN KARLSRUHE ABSTRACT NO.91163050, RODRIGUEZ 'IMMUNOGLOBULINS STIMULATE CENTRAL NERVOUS SYSTEM REMYELINATION:ELECTRON MICROSCOPIC AND MORPHOMETRIC ANALYSIS OF PROLIFERATING CELLS'	23-30
A	& LAB INVEST, (1991 MAR) 64 (3) 358-70 see abstract ---	1-22,31
X	WO-A-92 04442 (UNIV CALIFORNIA) 19 March 1992 see page 19, line 6 - page 24, line 14 ---	23-30
X	NEUROLOGY, vol. 42, no. 2, February 1992 pages 348-357, RODRIGUEZ ET AL 'IMMUNOSUPPRESSION PROMOTES CNS REMYELINATION IN CHRONIC VIRUS-INDUCED DEMYELINATING DISEASE' cited in the application see the whole document ---	23-30
P,X	THE JOURNAL OF IMMUNOLOGY, vol. 154, no. 5, 1 March 1995 pages 2460-2469, MILLER ET AL 'A MONOCLONAL AUTOANTIBODY THAT PROMOTES CENTRAL NERVOUS SYSTEM REMYELINATION IN A MODEL OF MULTIPLE SCLEROSIS IS A NATURAL AUTOANTIBODY ENCODED BY GERMLINE IMMUNOGLOBULIN GENES' see the whole document ---	1-31

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INTERNATIONAL SEARCH REPORT

Internat. Application No
PCT/us 95/05262

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	THE JOURNAL OF NEUROSCIENCE, vol. 14, no. 10, October 1994 pages 6230-6238, MILLER ET AL 'MONOCLONAL AUTOANTIBODIES PROMOTE CENTRAL NERVOUS SYSTEM REPAIR IN AN ANIMAL MODEL OF MULTIPLE SCLEROSIS' see the whole document ---	1-31
P,X	PROGRESS IN BRAIN RESEARCH, vol. 103, 23 December 1994 pages 343-355, RODRIGUEZ ET AL 'IMMUNE PROMOTION OF CENTRAL NERVOUS SYSTEM REMYELINATION' see the whole document -----	1-31

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 95/05262

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 1-4,22
because they relate to subject matter not required to be searched by this Authority, namely:
Remark: Although claims 1-14,22 are directed to a method of treatment of the human/animal body the search has been carried out and based on the alleged effects of the compound/composition.
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

Information on patent family members

PCT/us 95/05262

**Patent document
cited in search report**

Publication date

Patent family member(s)

Publication date

WO-A-9204442

19-03-92

AU-A-

8864691

30-03-92